

The Flu: Where It Hides, How to Beat It

ALSO: SPACE TOURISM, ULTIMATE AMATEUR DRONE, KEYSTONE XL, AND THE HAZARDS OF HEALTHY EATING **+ MIKE ROWE** ON AWESOMELY AWFUL JOBS

POPULAR SCIENCE

FEBRUARY 2015

SPECIAL REPORT

PG.32

**HAVE
WE FOUND**

ALIEN

IT'S NEW, IT'S WEIRD, AND IT'S LIVING AMONG US

LIFE?

PLUS! WHY
HACKING
IS GOOD
PG.18

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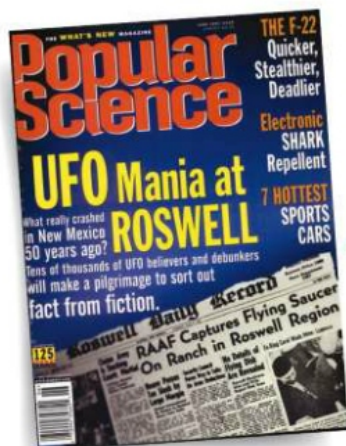
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FEBRUARY 2015 • **FEED**

A Bit About Us

ALIENS IN OUR ARCHIVES



MARCH 1967

Conspiracy theorists tout a government plot to conceal the truth about flying saucers. *Popular Science* finds the evidence second-hand and slim.

JUNE 1997

Fifty years after a UFO supposedly crash-landed in Roswell, New Mexico, the city turns the infamous event into a draw for global tourism.

JUNE 1994

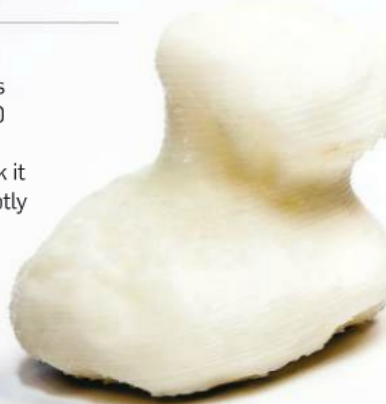
Astronautics engineer Robert Zubrin proposes that radiation emitted by interstellar spacecraft could be the key to finding aliens as they zip by.

JANUARY 2007

The French beam a TV show called *Cosmic Connexion* toward a star system 45 light-years away. The target audience? Aliens, of course.

A 3-D-PRINTED COMET

XYZprinting was kind enough to let us borrow a da Vinci 1.0 AiO 3-D printer and scanner, and we took it for a spin. We promptly printed a model of Comet 67P/Churyumov-Gerasimenko and confirmed, yes, it does look like a Rubber Ducky.



Short Review of a Long Book

Finally, scientists and academics get a chance to vent about their most hated subjects: the universe, individualism, and more.



This Idea Must Die: Scientific Theories That Are Blocking Progress
Edited by John Brockman

STRANGEST THING SENT TO THE OFFICE THIS MONTH

A piece of unprocessed cotton, stem and all



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**TAKE A DEEP BREATH**

A tour of one of the world's most important, least understood, potentially dangerous, possibly life-saving substances: air.

MICHAEL ROSENWALD

PAGE 52



Featuring

HAVE WE FOUND ALIEN LIFE?

Microbes that eat and breathe electrons have forced scientists to reimagine life—on this planet and possibly others.

COREY S. POWELL

PAGE 32

INSTRUCTIONS NOT INCLUDED

What does the disappearance of the common manual say about us?

MARK SVENVOLD

PAGE 40

THE WORST JOBS IN SCIENCE

Think your job's bad? These 10 down-and-dirty occupations are hard, dangerous, and outright gross, but people love them anyway.

BOB PARKS

PAGE 44

SLIPPERY TRUTHS

The proposed Keystone XL pipeline is the subject of seemingly endless debate. Here's what the data says.

KATIE PEEK

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From the Editor

Aliens Among Us

For scientists, few questions inspire as heated a debate as, *What is life?* You'd think we'd have that one down by now. But it turns out that defining life is really difficult. Go too narrow and it's arbitrary, like you're drawing a line in the sand. Go too broad and it's meaningless, like there's no line at all. A lot of

scientists say they would prefer to leave the business of a precise definition up to philosophers.

Instead, researchers tend to focus on a few characteristics indicative of life, namely metabolism, growth, reaction to stimuli, and reproduction. Among those, metabolism is often viewed as the first among equals. After all, without some way to transfer energy for storage or use, organisms couldn't grow, react, or reproduce.

The nice thing about metabolism

is that it's pretty universal. Every known organism harnesses energy in one of only a few ways. Or at least, that's what we thought.

In this month's cover story, writer Corey S. Powell investigates the discovery of a new form of life. The microbes, found—of all places—in the mud off Catalina Island, California, do not metabolize energy like any organism scientists have ever seen. They eat and breathe electricity directly. That's the equivalent of sticking your finger

“
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tions suitable for life. Then probes found water and organic molecules on Mars, and the Kepler observatory spotted nearly a thousand exoplanets, at least 22 of which are potentially habitable.

And that's the rub with science. Every time we increase our powers of perception, we find the universe is more complex than we imagined and life more tenacious. In that sense, finding bizarre and seemingly alien life on this planet simply increases the odds that we'll find it elsewhere. And when that happens, well, we'll have a lot more to debate than a simple definition.

Enjoy the issue.

Cliff Ransom
Editor in Chief

into a light socket for a midmorning snack. From the perspective of known science, these creatures are weird—alien, even—and they're not alone. Now that scientists know what to look for, they are finding these strange electricity-eating organisms all over.

That poses an interesting question: If life so contrary to scientific understanding can exist on our own planet—a short ferry ride from Los Angeles, no less—what range of forms could it take on others? Perhaps we should have sent the equivalent of a lightning rod along to Mars with the *Curiosity* rover.

To some, this kind of force-you-to-question-everything discovery can be frustrating. It's like the more you learn, the less you understand. To me, it's inspiring. We used to think we were the center of the universe. Then Galileo and the telescope happened. We used to think that only Earth had condi-

Contributors



Corey S. Powell

As former editor-in-chief of *Discover*, Corey S. Powell had edited stories about Kenneth Nealson, so was intrigued to see him leading research on bacteria that consume electricity. The two finally met when Powell reported “Have We Found Alien Life?” (page 32). “He has long worked outside the mainstream,” Powell says, and remains “a gracious and great explainer.”



Megan Molteni

“What you can 3-D print as a consumer is still limited,” says writer Megan Molteni. But engineers are pushing those boundaries with new “inks.” While reporting on fisheries, Molteni learned about shrill, a 3-D-printable bioplastic made from shrimp shells and other proteins. It inspired her to explore the full array of printable products in “Our 3-D Printed Universe” (page 25).



Coin-Op Studio

For “The Worst Jobs in Science” (page 44), we asked bi-coastal brother-and-sister duo Peter and Maria Hoey to illustrate some truly disgusting jobs—so naturally, they brought humor to the task. After identifying the most dreadful aspects of each, they applied their trademark retro style, which Peter describes as being infused with the dignified yet deadpan humor of Buster Keaton.



Michael Rosenwald

It was a strange scent that led Michael Rosenwald down the rabbit hole of airborne disease science. “I’m a classic hypochondriac,” he says, so he set out to find the odor’s source. Rosenwald enlisted air hygienist Steven Welty, who introduced him to a little-known field of scientists researching airflow’s health impacts. He reports on their work in “Take a Deep Breath” (page 52).



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Peer Review

DIFFERENT BUILDING BLOCKS

Q: "How Habitable Is That Exoplanet?" [December 2014] was interesting, but I am curious why it seems to assume that extraterrestrial life must be similar to ours. Even on Earth there is biologically surprising life.

Russ Brown, Savannah, Ga.

A: Astronomers recognize that life could come in forms unlike ours, so they've expanded the definition of habitable to include planets very uninhabiting to humans (no coffee!). We describe some that might harbor microbes that eat and breathe rock in "Have We Found Alien Life?" (page 32).



HAVE A COMMENT?
Write to us at letters@popsci.com or to *Popular Science*
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LEAPS ABOVE THE REST

I have wanted to raise my own source of protein, and have thought about several possible options. I had considered trying to raise either chickens or rabbits, but it seems they would take up too much space. I got a can of crickets long ago, but they were greasy, kind of expensive, and not particularly good. But those mentioned in December 2014's "Best of What's New" sound like fun, and look fairly convenient.

Ralph Lake, Hagerstown, Md.



TWEET OUT OF CONTEXT

Unless they're really confident that it won't get loose, a liquid metal ball floating in a space station seems like a bad idea.
@BBAlpert

OUR NEW HOME ONLINE

In November, we launched the new popsci.com. We felt plenty excited about it, and we were happy to hear that many of you felt the same.

Popular Science was my favorite magazine growing up and has been my favorite website as well. In the past few years, though, I have preferred other science publications online. But today when I realized that you have a complete new website, I felt I had to thank you.

Spencer Willett, Gilbert, Ariz.

interesting, and wide-ranging content.

Paul Berry Jr., Richmond, Maine

Had any issues with the site? We're always listening and updating. Email us at webmaster@popsci.com.

Popular Science lives a long, well-worn life at my house. I read it sometimes several times over several years. I found the old website an interesting extension of the magazine, but it was just okay . . . until now. Your new site is awesome! You have set a new standard for in-depth,



IS THAT YOU, TONY STARK?

Several of your "Best of What's New" [December 2014] researchers note that they would like improved battery technology and more electric vehicles (EVs) on the road. Aside from obvious advantages—greenness, for one—a breakthrough battery could also change global politics. If we rely primarily on EVs for our transportation needs, we could avoid many of the petroleum-fueled international conflicts so common today. Elon Musk seems to be leading this charge, what with Tesla's Gigafactory, the success of the Model S, and Solar City. Maybe Musk is a real-life Iron Man in disguise.

Bill Dale, Los Angeles, Calif.

SHOW & TELL

Not every job is a dream one, but some are downright terrible. This month, we tell you about some of the worst jobs in science (page 44). Now it's your turn to share:

Email your horror stories from the trenches and frontlines of the workforce to myworstjob@popsci.com.

We apologize . . . Since publication, the number of GM models that will be connected via 4G LTE has dropped to 31 from 34, as we reported on page 33 of December's issue and page 22 of November's issue. And on page 69 of the December issue, we wrongly referred to a laryngoscope as a laparoscope. Luckily our error was in print, not an operating room.

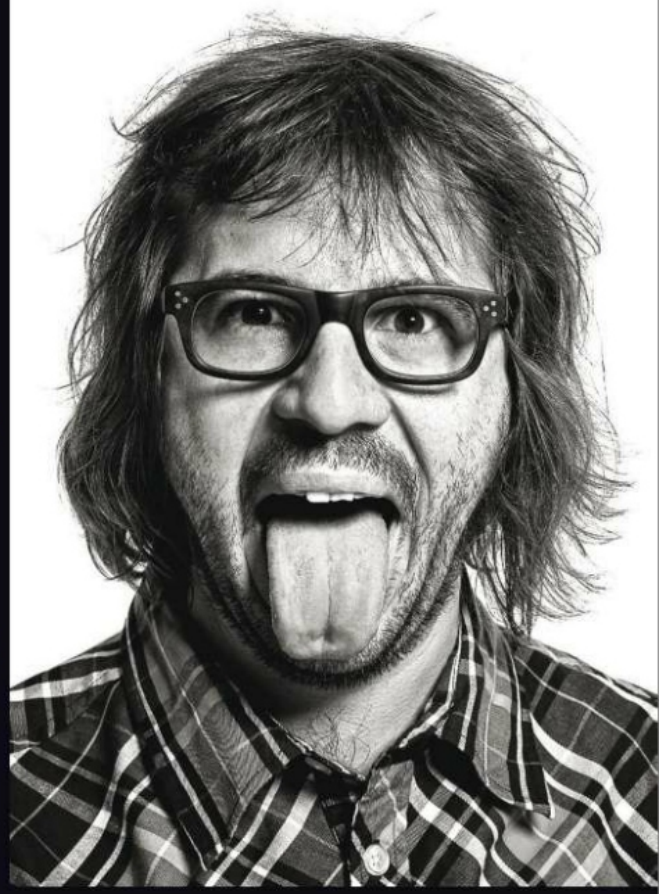
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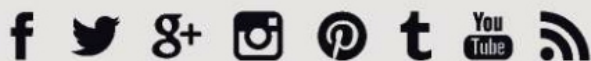
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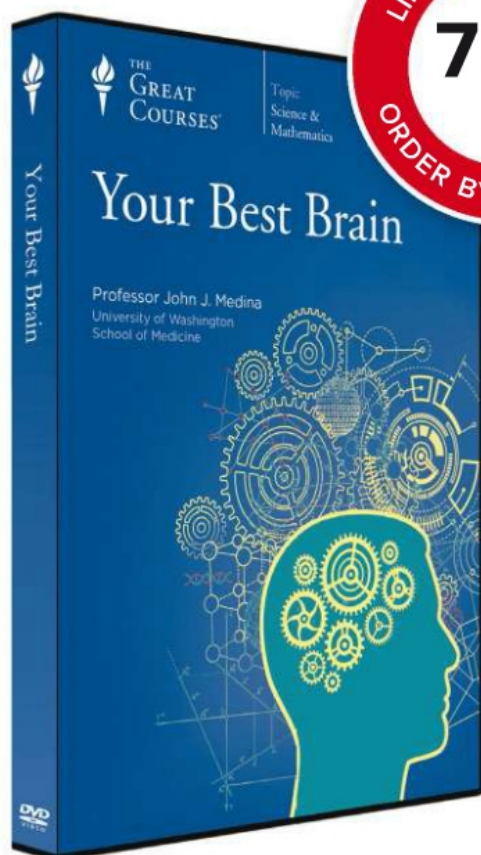
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"PEOPLE WANT CONVENIENCE AND HIGH-END CONTROLS. THE INSPIRE 1 HAS BOTH RIGHT OUT OF THE BOX."



THE BEST DRONE FOR ASPIRING FILMMAKERS

The use of recreational drones has exploded in the past few years—and so has the use of drones in Hollywood (cue the chase scenes in *Skyfall*). But amateur filmmakers still face a hurdle: Many consumer-grade drones don't come with a camera, and if they do, the equipment isn't very good. If you're just filming around the neighborhood, chances are you don't need the same setup as the one used to make a James Bond movie—but with the new DJI Inspire 1, you can get awfully close.

The Inspire 1 is the first consumer-grade drone that comes ready to

shoot 4K video. Largely derived from the Phantom 2, its best of class predecessor, the Inspire 1 adds performance to nearly every component of the drone and camera mount. "A lot of people are shooting on the Phantom 2 because of the convenience, but they want higher end controls," says Eric Cheng, director of aerial imaging at DJI. "The Inspire 1 applies those features right out of the box."

In order to eclipse the standards set by the Phantom 2, DJI reimagined the drone-building approach from the ground up. The company

replaced the Phantom 2's plastic arms with carbon fiber ones that rise above the vehicle's body once it's airborne, giving the gimbal-mounted 4K camera an unobstructed view in all directions. Two ultrasonic sensors and a downward-facing camera allow the vehicle to hold its position without GPS—necessary for anyone interested in filming indoors.

DJI also reworked its software so that two people can pilot, one to fly and one to film. "Dual-operator control is something that is typical in \$7,000-\$10,000 systems, but it's not something that has been seen at this price," Cheng says. The Inspire 1's gimbal and camera were designed to be modular, too, which means they can both detach. "Given the pace of DJI releases," Cheng says, "you can sort of imagine that this will likely not be the only camera that we offer."

MICHAEL NUÑEZ



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Obsessed

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LINDSEY KRATOCHWILL

1 MOLESKINE SMART NOTEBOOK

Moleskine and Adobe made a Creative Cloud-connected notebook that syncs digital and hand-drawn art. Scrawl your masterpiece on the page, and capture it with an app that renders it into vectors. **\$33**

2 PAWSCOUT PET FINDER

Pet tags can only help reunite you with your missing pet if someone takes the time to read them. Pawscout Pet Finder tags actively help find wayward pets with an embedded Bluetooth antenna. The tag sends a smartphone alert if Fido wanders too far—and helps home in on his location when he runs away. **\$30**

3 QUIRKY OUTLINK

When paired with a Quirky Wink hub, this smart outlet lets users monitor the electricity flowing to devices, turn the outlet on or off, and program schedules. **\$50**

4 WORX CLAMPING SAWHORSE

Integrating two tools, Worx's new sawhorse has a simple groove that fits two clamps. Hold your projects in place, and fold it all away for storage when you're finished. **\$69**

5 DYSON CINETIC BIG BALL ANIMAL

Vacuums are convenient. Changing their bags and filters—not so much. To end that aggravation, Dyson modified its bagless

vacuum to make it filterless too. Cinetic has tiny flexible cones that vibrate to capture every particle without clogging. **\$600**

6 TAYLORMADE R15 DRIVER

The new R15 golf club has two sliding weights that can help straighten your shot, and a center of gravity that sits lower and more forward to help increase distance. **\$429**

7 NEXT GLASS

Next Glass aims to be Netflix for wine and beer selection. The app learns your preferences—and correlates them to a database of chemical compositions—to make recommendations. Scan a wine label with your smartphone and Next Glass decides whether you're apt to like it . . . or not. **Free**

8 THE MAN WHO TOUCHED HIS OWN HEART

In time for Valentine's Day, Rob Dunn's book tells true tales of the heart—just not the kind you'd expect. In 325 pages, Dunn details broken hearts, transplanted hearts, and the bar-fight beginnings of heart surgery. **\$27**

9 LINKAGE

Learning genetics can be tough, unless you're doing it with Linkage. The card game challenges players to build the longest strand of RNA, while mutating that of their opponents. It also teaches players how to accurately match DNA and RNA. **\$18**

10 EARTH A NEW WILD

In five episodes, Dr. M. Sanjaan travels to 29 countries to seek out baby pandas, humpback whales, and other extraordinary wildlife, while exploring the ways humans shape the natural world, and vice versa. **Feb. 4 on PBS**



FROM TOP LEFT: COURTESY MOLESKINE; COURTESY DYSON; COURTESY QUIRKY; COURTESY TAYLORMADE; COURTESY PAWSCOUT; COURTESY NEXT GLASS; COURTESY TAYLORMADE; COURTESY GENIUS GAMES; COURTESY LITTLE, BROWN AND COMPANY;



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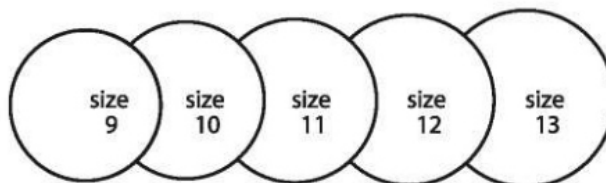
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Trending

2003

The year the first commercial gesture-control device, a PlayStation 2 accessory called the EyeToy, was released.

Gesture Control for Mobile Devices



In 2010, Microsoft popularized gesture controls with the release of the Kinect. In its first 60 days on sale, the device sold 133,000 units per day, a Guinness World Record. Three years later, Leap Motion brought the same capabilities to personal computers. But both devices required stationary sensors to perceive movements, so users couldn't stray too far. Now, a new set of devices—outfitted with ultrasound, electromyography (EMG) sensors, and inertial sensors—are allowing the use of touchless interfaces anywhere. **LINDSEY KRATOCHWILL**



Nod Labs

Polite or no, pointing is a universal human gesture, so Nod Labs decided to leverage it. The Nod ring includes inertial sensors, such as accelerometers and gyroscopes, that enable pixel-level control on any interface. That means smartphones, tablets, laptops, and TVs can be controlled with the wave of a finger, or for more complex commands, two or three fingers. **\$149**

Elliptic Labs

Instead of building hardware, Elliptic Labs focused on software. Its technology prompts smartphone speakers to emit high-frequency sound waves. When a user moves his or her hand over the screen, a microphone picks up the reflected sound waves and translates them into a command. The company is now working with manufacturers to optimize speakers for better accuracy.

Thalmic Labs

Myo, made by Thalmic Labs, is worn on the forearm. It uses EMG sensors to pick up the electrical signals produced when your brain sends a command to your fingers. Software interprets signal patterns as gestures, such as making a fist, snapping your fingers, or raising your arm. Myo works with many popular Bluetooth-enabled devices right out of the box. **\$199**

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PABLOS HOLMAN WANTS YOU TO BREAK YOUR GADGETS

In the past year, Apple, Sony, and Home Depot were targeted in notorious criminal hacks. But not all hackers are bad. Pablos Holman, an inventor and hacker at patent firm Intellectual Ventures' (IV) Laboratory, breaks electronics every day—and he thinks more people should be doing the same.

Popular Science: You've worked on spaceships with Amazon CEO Jeff Bezos, 3-D printers at Makerbot, and now at IV, you're working on a vaccine storage device. What's the common thread?

Pablos Holman: Everything I've done in my career has been about taking computers and putting them to use in places they weren't used before. In my mind, I've always had a grand vision of that. I've always thought it was important to use computers to solve big problems.

PS: What exactly do you mean?

PH: Pretty simply, more people should be focused on finding new applications for computers. Adding a

"HACKING IS JUST A LEARNING STYLE OR METHODOLOGY. RATHER THAN RELYING ON THE INSTRUCTIONS, WE'LL TRY EVERYTHING."



computer to something is the easiest way to give it features and make it more reliable. Of course, when you do that—to a car, plane, or anything else—you also inherit some of the security problems of a PC.

PS: Should we be alarmed at the increasing cyber security threats?

PH: Yes. Whether you're talking about a computer, phone, car, or plane—they're all using the same kinds of operating systems and chips, so they're all susceptible to the same types of attacks. And we don't really know how to fix this. I worked in computer security for a long time before I realized [security experts] were never going to win.

PS: Can you be proud to call yourself a hacker if most people associate the term with criminal activity?

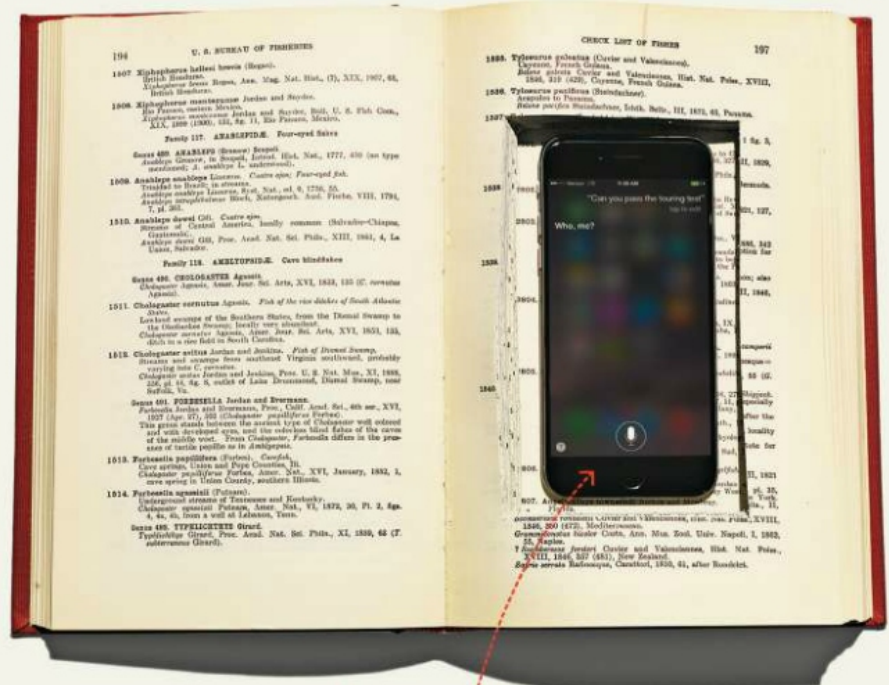
PH: I don't think it's particularly weird or audacious. Hacking is just a learning style or methodology. Rather than relying on the instructions, we'll just try everything. We'll take something apart, break it into a lot of little pieces, and figure out what we can build from it. Now that computers are in everything, hackers are more relevant than ever.

PS: Should we worry about unfettered anonymity online?

PH: No. I worked on tools in the past to try to preserve anonymity on the Internet. The model user for those tools is not a criminal. It's a human rights worker who is trying to document atrocities. And you get some risk with that. The bad guys can use the tools, too. But fundamentally, anonymity online is unstoppable.

PS: Is the world better or worse because of hackers?

PH: You don't find a lot of people whose business card says inventor or hacker. They're not legitimate career choices, and I just think that's really sad. It only seems unusual to be a hacker or inventor because we don't have enough competition. Hopefully, [IV] will see enough success that more people will think it makes sense to do it. (Edited and condensed by Michael Nuñez) 



HOW SMART IS YOUR AI?

In 1950, Alan Turing, a pioneer of artificial intelligence (AI), proposed what's now known as the Turing Test—an evaluation of a machine's ability to behave like a human. Though there's still plenty of room to improve, many AI systems are nearing Turing's benchmark. And as they do, AI on our phones, TV game shows, and IT systems are sounding more like us than ever before. **CORINNE IOZZIO**

SCALE:

For artificial intelligence—just as with people—knowing the answer to a question (the “book smart” end of our spectrum) is only half the equation; a little bit of contextual awareness (or “street smarts”) goes a long way.

BOOK SMART

1

APPLE SIRI

By accessing information on an iPhone, in apps, and online (think Wikipedia), Siri handles simple tasks and can answer straightforward questions. It can look up the weather, direct you to a meeting—or even help settle a bar bet.

2

MICROSOFT CORTANA

Prior questions (and answers) help this Windows Phone assistant establish context. It also learns the nuances of a user's speech. For instance, if you refer to your home as a “pad,” Cortana will learn to identify your intended meaning.

3

GOOGLE'S VOICE SEARCH

Google's voice search can answer follow-up questions, and it can figure out exactly what a person is referring back to. For example, “What team does Tony Romo play for?” can be followed by “How tall is he?” or “When's the next game?”

4

IBM WATSON

Using Watson, developers can create applications that analyze complicated data sets (like medical records). The system can then assist in diagnosing and prescribing treatments. It can also engage in a give-and-take dialogue with users.

5

IPSOFT AMELIA

This commercial AI system used for virtual service desks adds emotional awareness to its machine-learning capabilities. The platform replaces automated customer-service phone trees and responds empathetically to people.

STREET SMART

At Long Last... the Tweel

Fifteen years ago, Michelin set out to build a tire that would never go flat. While the prototypes gained worldwide attention, and the military has been using the technology since 2013, consumers and businesses have been locked out.

No longer. In November, Michelin began making its long-awaited airless tire and wheel combo, dubbed the X Tweel, available for use on select commercial vehicles.

Unlike pneumatic tires, which cushion rides using a bed of pressurized air, the X Tweel uses a combination of deformable polyurethane spokes, a steel-and-rubber outer rim, and rigid metal hub. The outer rim—called a shear beam—carries most of the load. The spokes and hub distribute the load across different parts of the shear beam as the tire rolls over objects.

John Deere is one of the first companies to adopt the X Tweel and is already using them on popular **ZTrak** series mowers. "[The Tweel] lasts two to three times longer than the previous or current tires," says Chase Tew, a manager of commercial mowing at John Deere.

For now, the X Tweel will serve only slow-moving vehicles. The factory, which began production in November, makes tires for machines like skid-steer loaders and lawn-mowers (at high speeds, airless tires tend to vibrate and make lots of noise). But Michelin would like to extend the product line in the future. Ralph Dimenna, the vice president of Michelin Tweel Technologies, says he could see small utility vehicles like golf carts using airless tires in the next few years. Ultimately, he hopes to see automobiles join the revolution as well—though for now, you'd better keep a spare in your trunk.

ALISSA ZHU



The John Deere Z950 (pictured below) is one of the first vehicles to feature the Michelin X Tweel Turf.



**50
MILLION**

Number of dollars Michelin spent on the world's first plant dedicated solely to the production of airless radial tires

The Parts

Shear beam: This is the outer rim of the tire. It carries the vehicle's load. Rubber treads give it traction.

Polyurethane spokes: These push and pull the load across the shear beam as the tire deforms.

Hub: This pulls on the spokes and hangs the load from the top of the shear beam during operation.

A Cell Network That Targets Dead Zones

PROBLEM

If you live in or near a city, it's hard to imagine not finding a cell signal. Telecommunication companies spend hundreds of millions of dollars on cell towers and bulky base stations. The trouble is, they'll only install them in places where the network will get ample use. Sparsely populated areas usually don't qualify, and that means more than an estimated one billion people worldwide lack access to reliable phone and Internet service.

SOLUTION

Kurtis Heimerl enables entrepreneurs to build their own wireless networks. A postdoctoral student at the University of California at Berkeley, Heimerl packed a Linux computer, a 900 MHz power amplifier, and a 2G cellular-network antenna into a microwave-size box called Endaga CCN1. It costs a relatively modest sum of \$6,000 and is simple to set up: Plug in power and Internet, mount the unit to a tree or pole, and voilà: connection.

MICHAEL NUÑEZ

1,000

Number of people in a 6-mile radius who can connect through Endaga at a time



PHOTOGRAPH BY BRIAN KLUTCH

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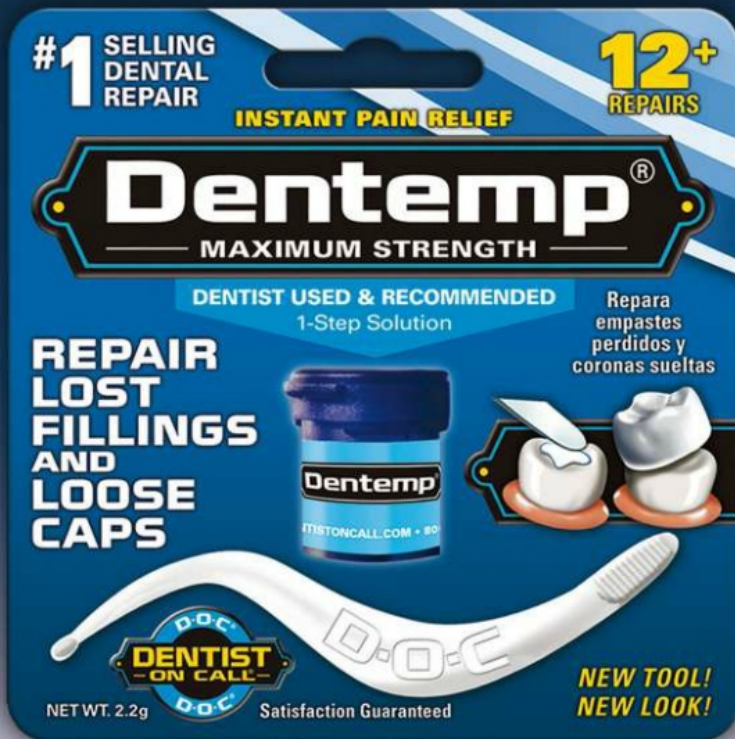
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Next

EDITED BY **Jen Schwartz & Breanna Draxler**



A month after snapping this selfie with comet 67P/Churyumov-Gerasimenko, the *Rosetta* spacecraft achieved a historic first: Its Philae lander touched down on the comet's surface. Philae confirmed the presence of organic molecules—possible building blocks of life—before its sun-starved batteries died. *Rosetta* will continue to orbit 67P as it hurtles toward our home star, providing an unprecedented look into comet anatomy as dust and frozen gas heat up, escape the nucleus, and stream into space.

The Big Idea

STRIVING FOR THE PERFECT DIET IS MAKING US SICK

Man cannot live on kale alone

↓

Americans today have a complicated relationship with food, to put it kindly. Sure, mega-portioned processed meals and spiking rates of diabetes still dominate headlines. But in a climate that now includes \$70-a-day juice cleanses, four gluten-free lifestyle magazines, and a “superfoods” industry set to hit \$130 billion in 2015, we’re also a culture fascinated with achieving some perceived pinnacle of well-being.

As a growing number of people dramatically retool their diets in the pursuit of health, some are cutting out half the categories on the food pyramid altogether. In certain cases, this hyper-controlled eating becomes a compulsion, and the anxiety of consuming something

deemed “bad for you,” like a piece of cheese, feels paralyzing. The result is a new kind of eating disorder doctors are calling orthorexia. A recent case study defines it as “a pathological obsession for biologically pure and healthy nutrition.” Co-author Thomas Dunn, a psychologist at the University of Northern Colorado, explains that just as anorexia is driven by a fear of being fat, orthorexia is driven by a fear of being unhealthy. The former fixates on quantity, the latter on quality.

Such draconian diets can lack essential nutrients, and they make the vitamins and minerals a person *does* get from meals of exclusively, say, leafy greens, impossible for the body to absorb. This can lead to fragile bones, hormonal shifts, and cardiac problems, along with psy-

chological distress and entrenched, delusional thinking. In other words, the opposite of the intended effect.

Because orthorexia was first identified less than 20 years ago, there’s no real estimate of how many people have the disease. “Our culture is promoting health now, which is great,” says Sondra Kronberg, a spokesperson for the National Eating Disorder Association. “But people of certain temperaments take healthy eating to an extreme.” They agonize over sourcing and cooking methods, isolate themselves from social situations, and develop magical thinking about what certain foods can do.

Worse, many people now self-diagnose conditions like non-celiac gluten intolerance, ripping through every online FAQ and testimonial they can find. Peter Green, director of the Celiac Disease Center at Columbia University, encounters this scenario routinely. “We see patients who don’t know

Just as anorexia is driven by a fear of being fat, orthorexia is driven by a fear of being unhealthy.

what to eat anymore because they identify food as the source of all their issues,” he says.

Prescriptive books, blogs, and social media expose a vulnerable population—informed, sensitive, Type-A people—to behaviors that may hurt them, says Jennifer Gaudiani, associate director of the ACUTE Center for Eating Disorders in Denver. And patients’ black-and-white thinking makes treatment tricky. “People need to relearn how to view food,” Dunn says.

For the vast majority, eating is, unsurprisingly, all about balance. “Sometimes you’re at a party and there are fries,” says Kronberg. “Your body really can handle that one meal.” **JEN SCHWARTZ**

INKS OF THE FUTURE**METAL**

Advanced lasers that fuse metallic powders enable printers to make parts more durable than cast metal and comparable in strength to forged. GE now plans to 3-D print tens of thousands of fuel nozzles for its new, lower-emission jet engines.

HUMAN CELLS

Scientists can now print with living human stem cells. They can also use printing to create the blood vessels necessary to deliver oxygen and nutrients to that tissue. Next up: functioning organs, such as the pencil-tip-size livers introduced last year for pharmaceutical testing.

SHRILK

Created from discarded shrimp shells and the protein from silkworm fibers, Shrilk serves as a light, durable alternative to plastic filament. It's cheap to fabricate, food-safe, biocompatible, and only takes two weeks to break down in a compost bin.

GRAPHENE

In 2014, researchers printed a proto-battery from polymers infused with graphene, a material that's incomparably strong, flexible, and conductive. Printing improvements could potentially lead to electronics that are 1,000 times faster than today's, with unbreakable touchscreens printed on them.

OUR 3-D-PRINTED UNIVERSE

What was a niche prototyping tool 25 years ago is fast becoming a globally competitive manufacturing method. Today's 3-D-printing industry is worth well over \$2 billion, and experts estimate it'll climb to five times that by 2021. A staggering variety of items now populate the printed landscape: Many are bizarre one-off experiments, but some are poised to reshape the world we live in, one layer at a time. **MEGAN MOLTENI**

PARADIGM-SHIFTER**Drones**

The print-on-demand drone developed for the Department of Defense can cruise at 40 mph for 45 minutes.

**Houses**

A portable printer cranks out mini houses made from a mix of local materials like mud, clay, straw, and even wool. A bigger version, with a 4-inch extruder nozzle, will soon produce actual dwellings.

**Dental Work**

For a perfect fit, lab technicians can print retainer molds, crowns, and bridges to the exact dimensions of a patient's teeth.

**Cars**

It took 44 hours to produce the plastic seats, chassis, and fenders for the first 3-D-printed car. Adding tires, suspension, and a motor made it ready to roll.

Furniture

Rest your weary bones on a custom 3-D-printed chair. No word yet on ottomans.

**Guns**

Plans for a plastic handgun called the "Liberator" were downloaded 100,000 times in two days before the Department of State requested they be taken down.

"Bump" Keys

With the right software, printing a key that can open almost any lock requires only a photograph of the keyhole. Watch out!

Microbatteries

Last year, scientists used anode and cathode inks to print lithium-ion batteries the size of a grain of sand.

**Medications**

Powdered pharmaceutical inks have been printed into drugs. Custom doses of ibuprofen and cancer meds may be on their way.

**New Skin**

Layers of skin cells printed directly onto a burn wound could one day replace grafting.

**Better Bones**

Doctors can use the CT scan of a bone defect to print a scaffold for growing new bone from a patient's cells.

**Personal Power**

A 3-D-printed wind turbine fits in a backpack and can churn out enough power to charge a phone or laptop.

**Farm Tools**

Female farmers in rural Africa are designing hand tools tailored to their particular soils, crops, or body mechanics.

**LEDs**

A printed stack of metals and polymers shuttle current to a layer of nanoparticles, which emit light.

**Space Food**

A printer can already lay down sheets of flavored nutrient-rich food powders. A similar machine may one day nourish Mars-bound astronauts.

JUST FOR KICKS

PRINT-READY

IN THE WORKS

Points of Interest

Why You Shouldn't Fear the Electric Car



In the quest to get drivers to swap their gas-guzzlers for electric vehicles (EV), the greatest barrier is not, surprisingly, the cost. It's range

"FEW BUYERS WANT A FIRST-GENERATION ANYTHING, BUT DRIVERS ARE MORE WILLING TO ADOPT SECOND OR THIRD GENERATION EVS."

—**Tom Turrentine**, Director of the Plug-In Hybrid and Electric Vehicle Research Center at the University of California, Davis

anxiety: the fear that a battery-powered EV might go kaput mid-trip. Some of that skittishness stems from a lack of clarity into how EVs work. But manufacturers are to blame too. Existing range-estimation systems are, actually, somewhat unreliable, since they depend on limited data sets. To remedy the problem,

engineers at North Carolina State University developed an algorithm that's up to 20 percent more accurate at calculating range. It uses driving habits, weather, terrain, and the battery's age and condition. Now they're hoping car companies come knocking: The more drivers know, the more alluring EVs will seem. **MAC IRVINE**

200K

Number of EVs registered in the U.S. More than one-third of those are found in California.



HOW DRIVING SCENARIOS AFFECT RANGE

Highway Commute

- In an EV, the higher the speed, the more energy it requires. Highway ranges are typically about 20 percent less than city ones, which is the opposite of gas-powered vehicles.
- Batteries produce weaker current in cold, wintery weather. According to the American Automobile Association, an EV's range at 20°F is about 60 percent less than it would be at 75°F.



The average American drives less than 40 miles a day, and EVs like the Nissan Leaf (above) go twice that far on a single charge. The 265-mile range of the Tesla Model S is the industry's gold standard.

Urban Gridlock

- As a battery ages, its capacity wanes. For cars in heavy use—such as a New York City taxi, which travels five times as much as the average American vehicle—the range will drop more quickly over time.
- Stop-and-go traffic translates to wasted gas, but EVs use very little power while idling (and even recoup some with regenerative braking). City driving can actually improve an EV's range by up to 25 percent.

Mountain Passes

- Combustion vehicles use excess engine heat to warm a car's interior on a chilly day. But any heat in an EV—and in fact all accessories including audio and built-in navigation—draws down the battery, reducing the range.
- Like their gas-powered counterparts, EVs operate more efficiently on smooth, flat surfaces, so steep, mountainous terrain and dirt roads limit range as well.



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Geeking Out

Cori Bargmann

On Probing the Brain

Arguably more ambitious than the Human Genome Project or the Apollo program, the BRAIN Initiative endeavors to demystify our least understood organ—and the one that makes us most human. Announced by President Obama in 2013, the 12-year, \$4.5-billion undertaking aims to establish links between brain function and behavior, and to develop tools that will help us finally get to the bottom of conditions such as Alzheimer's, autism, and depression. As the project's planning co-chair, Rockefeller University neurobiologist Cori Bargmann spent the past year assembling expert teams and vetting research ideas. Now, she says, the real work begins.

200

Estimated cost, in billions of dollars, that the U.S. spends annually to care for dementia patients

“

I don't expect science to be at the very top of the political agenda. But a whole lot of scientists—and the president himself—said this is the time to figure out the brain. We began by organizing workshops with thousands of researchers in different fields, asking questions about brain chemistry, imaging, and tools: What do we have? What's on the horizon? What do we really need?

In the past century of neuroscience, there's been a lot of analysis of individual neurons and synapses, and, more recently, imaging of the whole brain. But we scientists think everything of substance happens in between these two scales. It's as if you're studying New York City with a microscope and satellite images. But what you really want is to look at it on a human scale.

To study that intermediate level, our microscopy and optogenetics technology—despite how far it's come—still needs to be 100 times better. So the initiative is bringing together experimentalists and theorists from different disciplines, well beyond neuroscience. DARPA, for example, is interested in developing hardware to treat soldiers' PTSD. Our goal is to build up the science and the tools so that everyone can use them.

Within a couple of years, the BRAIN Initiative could enable us to answer at least basic questions, like how many different kinds of cells are in the brain. We want to see the interconnected nerves that give rise to thoughts, actions, and emotions. And we are taking lessons from the brain to make computers more like networks of neurons, which don't draw much power at all. Will we understand the basis of consciousness or creativity? No, I think not. You can't plant a flag in it that way. But maybe we'll discover them by accident. This is science, not engineering. In engineering, you know exactly where you're headed. In science, you don't know where you're going until you get there. **AS TOLD TO BREANNA DRAXLER**

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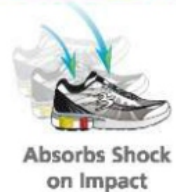
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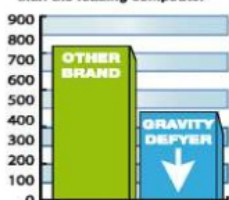
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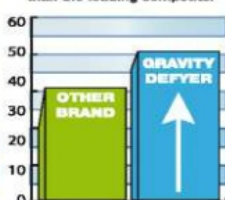
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SHOCK ABSORPTION STUDY HPW Biomechanics, 2012

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Subjective Measures

Will Space Tourism Survive the Crash of SpaceShipTwo?

Yes—but it's going to take a lot more cash and a major shift in expectations

↓
Aspiring space tourists placed high hopes on Virgin Galactic's SpaceShipTwo (SS2), many of whom plunked down upwards of \$200,000 for a future ticket into suborbit. But on October 31st, the rocket-propelled vehicle broke apart during a test flight above the Mojave Desert. One pilot parachuted to safety; the other didn't survive. As footage of the wreckage and speculation about the cause flooded the news, many wondered if we were witnessing not just the smoking remains of a single experimental vessel, but of the nascent space tourism industry as well.

At this point, it's unclear how the crash might affect Virgin Galactic (VG)—already behind schedule and over budget—but it will almost assuredly alter how we approach sending civilians to the thermosphere. Upstart space-tech firms like VG, SpaceX, Blue Origin, and XCOR Aerospace pride themselves on moving faster and more efficiently than NASA and its cadre of contractors, including Boeing and Lockheed Martin. Rather than the billions of dollars associated with manned spaceflight missions before it, VG had reportedly spent an estimated \$500 million. That's admirable—and certainly efficient—but it's far too little to create a fleet of reusable vehicles that ferry passengers into suborbit several times a week. Consider, for example, the humble business jet. Dassault Aviation, a company with decades of experience in aircraft design and manufacturing,

likely invested upwards of a billion dollars to develop a single plane, according to industry analysts. Its new Falcon 5X carries a comparable number of passengers with SS2 and doesn't have to go to space.

Taking that as a guide, VG would need to be, at least, a \$2 billion program. But can any company afford to do private space safely? Marco Caceres, a space-industry analyst at Teal Group, named one contender: SpaceX. Founder Elon Musk's company is positioned for success because it's financing its development with commercial and government clients, not celebrities. "That sort of funding won't come from a few hundred adventure seekers," Caceres says. "It's going to take big-time investment."

Beyond cash, the commercial space industry needs to also begin managing its expectations. That

CAN ANY COMPANY AFFORD TO DO PRIVATE SPACE SAFELY?

starts with acknowledging that private-space travel is decades away, not years. There's plenty of enthusiasm—even within NASA—surrounding the transition of space access from government monopoly to private competition. But pushing that shift forward too hastily, as we've seen, can be dangerous. The pace of progress needs to be defined by the unique challenges of spaceflight, not any one company's desire to reach suborbit and beyond. **ERIC ADAMS**



Chicago Doctor Invents Affordable Hearing Aid

Outperforms Many Higher Priced Hearing Aids

Reported by J. Page

CHICAGO: A local board-certified Ear, Nose, Throat (ENT) physician, Dr. S. Cherukuri, has just shaken up the hearing aid industry with the invention of a medical-grade, affordable hearing aid. **This revolutionary hearing aid is designed to help millions of people with hearing loss who cannot afford — or do not wish to pay — the much higher cost of traditional hearing aids.**

"Perhaps the best quality-to-price ratio in the hearing aid industry" — Dr. Babu, M.D.
Board-Certified ENT Physician

Dr. Cherukuri knew that untreated hearing loss could lead to depression, social isolation, anxiety, and symptoms consistent with Alzheimer's dementia. **He could not understand why the cost for hearing aids was so high when the prices on so many consumer electronics like TVs, DVD players, cell phones and digital cameras had fallen.**

Since Medicare and most private insurance do not cover the costs of hearing aids, which traditionally run between \$2,000-\$6,000 for a pair, many of the doctor's patients could not afford the expense. Dr. Cherukuri's goal was to find a reasonable solution that would help with the most common types of hearing loss at an affordable price, not unlike the **"one-size-fits-most" reading glasses** available at drug stores.

- **Designed By A Board-Certified Ear, Nose and Throat (ENT) Doctor**
- **Doctor-Recommended, Audiologist-Tested**
- **★★★★★ Top rated hearing aid online —thousands of satisfied customers**
- **FDA-Registered**
- **Save Up To 90%**
- **Free Shipping Available**
- **Batteries Included! Comes Ready To Use**
- **100% Money Back Guarantee**



He evaluated numerous hearing devices and sound amplifiers, including those seen on television. Without fail, almost all of these were found to amplify bass/low frequencies (below 1000 Hz) and not useful in amplifying the frequencies related to the human voice.

Inspiration From a Surprising Source

The doctor's inspiration to defeat the powers-that-be that kept inexpensive hearing aids out of the hands of the public actually came from a new cell phone he had just purchased. **"I felt that if someone could devise an affordable device like an iPhone® for about \$200 that could do all sorts of things, I could create a hearing aid at a similar price."**

Affordable Hearing Aid With Superb Performance

The high cost of hearing aids is a result of layers of middlemen and expensive unnecessary features. Dr. Cherukuri concluded that it would be possible to develop a medical grade hearing aid without sacrificing the quality of components. The result is the **MDHearingAid® PRO**, well under \$200 each when buying a pair. **It has been declared to be the best low-cost hearing aid that amplifies the range of sounds associated with the human voice without overly amplifying background noise.**

Tested By Leading Doctors and Audiologists

The **MDHearingAid® PRO** has been rigorously tested by leading ENT physicians and audiologists who have unanimously agreed that the **sound quality and output in many cases exceeds more expensive hearing aids.**

DOCTORS AND PATIENTS AGREE: "BEST QUALITY SOUND" "LOWEST AFFORDABLE PRICE"

"I have been wearing hearing aids for over 25 years and these are the best behind-the-ear aids I have tried. Their sound quality rivals that of my \$3,000 custom pair of Phonak Xtra digital ITE." —Gerald Levy

"I have a \$2,000 Resound Live hearing aid in my left ear and the MDHearingAid® PRO in the right ear. I am not able to notice a significant difference in sound quality between the two hearing aids." —Dr. May, ENT physician

"We ordered two hearing aids for my mother on Sunday, and the following Wednesday they were in our mailbox! Unbelievable! Now for the best part—they work so great, my mother says she hasn't heard so good for many years, even with her \$2,000 digital! It was so great to see the joy on her face. She is 90 years young again." —Al Peterson

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RISK FREE
TRIAL**



Proudly assembled in the USA
from Domestic & Imported Components.



HAVE WE FOUND

The background of the entire page is a dark, textured surface covered with vibrant, colorful marbled patterns and splatters. The colors include shades of blue, green, yellow, orange, and purple, creating a complex, organic, and somewhat chaotic visual effect. The patterns resemble liquid paint or ink that has been manipulated, possibly through techniques like marbling or splatter art.

Microbes that eat
and breathe
electricity have
forced scientists
to reimagine how
life works—on this
planet and others

By **Corey S. Powell**

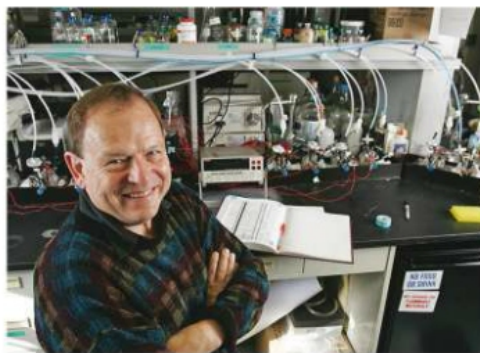


Kenneth Nealson is looking awfully sane for a man who's basically just told me that he has a colony of aliens incubating in his laboratory.

We're huddled in his modest office at the University of Southern California (USC), on the fifth floor of Stauffer Hall. Nealson is wearing a rumpled short-sleeve shirt, a pair of old suede loafers, white socks—your standard relaxed academic attire—and leaning back comfortably in his chair. An encouraging collection of academic awards hangs on one wall. Propped behind him is a well-worn guitar, which he sometimes breaks out to accompany his wife's singing. And across the hall is the explanation for his quiet confidence: beakers and bottles full of bacteria that are busily breaking the long-accepted rules of biology.

Life, Nealson is explaining, all comes down to energy. From the mightiest blue whale to the most humble microbe, every organism depends on moving and manipulating electrons; it's the fuel that living matter uses to survive, grow, and reproduce. The bacteria at USC depend on energy, too, but they obtain it in a fundamentally different fashion. They don't breathe in the sense that you and I do. In the most extreme cases, they don't consume any conventional food, either. Instead, they power themselves in the most elemental way: by eating and breathing electricity. Nealson gestures at his lab. That's what they are doing right there, right now.

"All the textbooks say it shouldn't be possible," he says, "but by golly, those things just keep growing on the electrode, and there's no other source of energy there." *Growing on the electrode.* It sounds incredible. Nealson pivots on his chair to face me and gives a mischievous



Kenneth Nealson discovered that *Shewanella oneidensis* can deposit electrons directly on minerals—"breathing" a solid substance—via tiny chemical wires.

grin. "It is kind of like science fiction," he says. To a biologist, finding life that chugs along without a molecular energy source such as carbohydrates is about as unlikely as seeing passengers flying through the air without an airplane.

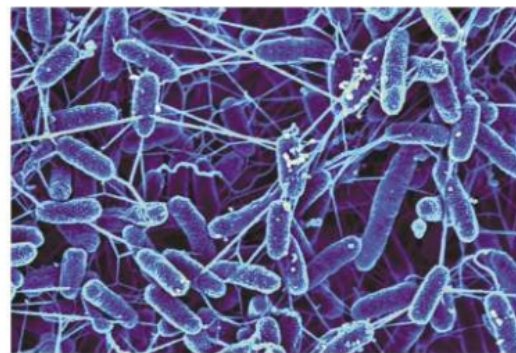
That discovery comes with some sizable implications. On a practical level,

electric bacteria could be harnessed to create biological fuel cells or to clean up human waste. Nealson tells me that one of his former students just got a grant to build a bacteria-powered sewage system. But more to the point, such microbes appear to comprise a vast, largely unexplored realm of life on this planet. There's a chance they are an important part of the biodiversity on planets beyond ours too.

Nealson never utters the word "aliens," but it hangs heavily over the conversation. His bacteria are unlike anything we've ever encountered, and they are forcing us to rethink life as we know it.

LIKE ANY GOOD ALIEN STORY, this one begins with an abduction—though one of a decidedly scientific variety. The abductee in this case was not a person but a mineral. Nealson settles in to tell the tale.

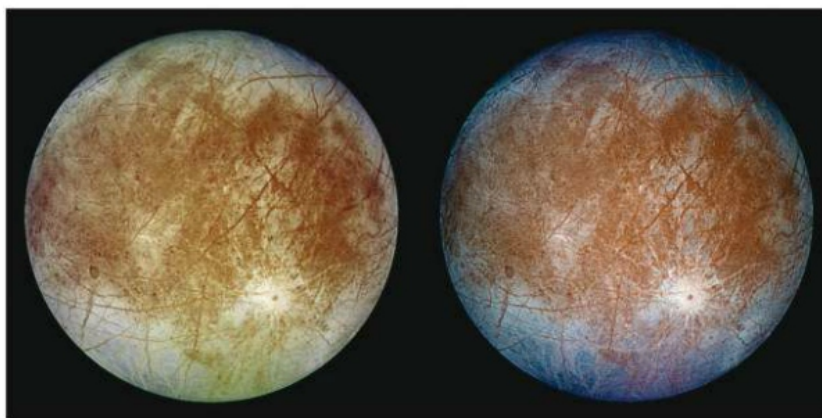
In 1982, he was a professor at the Scripps Institution of Oceanography when he heard about strange goings-on in Oneida Lake in upstate New York. Each spring, snowmelt washes manganese out of the surrounding mountains and into the lake. Winds then whip up the waters, allowing the dissolved metal to combine efficiently with oxygen to



form solid manganese oxide, which sinks to the lake bed. The trouble was, scientists didn't find nearly as much as they anticipated. Something was making the manganese oxide vanish, at more than 1,000 times the geologically expected rate, and nobody could figure out what.

"If rates were really that fast, I knew it

Jupiter's moon Europa (in true and enhanced color)



WHERE TO LOOK FOR LIFE IN SPACE

Our solar system boasts a number of places where life could possibly persevere. —CSP

Mars

Sure, we've been hunting life here for decades, but we may have been going about it the wrong way. Anything alive today probably lives deep underground, protected from radiation and temperature extremes; it might resemble deep, electrically active microbes on Earth. To look for Mars life: Drill, baby, drill!

Enceladus

Saturn's 300-mile-wide moon Enceladus is stretched and squeezed by gravitational interaction with its neighbors. The resulting friction heats its interior, and may power a system of hydrothermal vents below its south pole; such vents would be natural homes to rock-breathing microbes.

Mimas

Like its cousin Enceladus, this small Saturnian moon is an iceball that is heated by a tug-of-war with other, nearby satellites. Recent studies indicate that Mimas could be partly melted inside. Anywhere that water meets rock—even dozens of miles down—there is chemical energy available that could potentially power life.

Europa

At its heart, this large Jovian satellite (at 1,940 miles wide, a smidge smaller than our own) has an extensive ocean and possible undersea volcanoes. On occasion, water bursts from Europa's cracked, icy surface in large plumes. The proposed *Europa Clipper* spacecraft would investigate whether its conditions are conducive to life.

Ceres

The largest member of the asteroid belt is covered with clays and carbon-bearing minerals, resembling the carbon-rich meteorites that rained down on the early Earth. In March, NASA's *Dawn* spacecraft will begin an extended study of Ceres; it isn't equipped to look for life but could test for favorable chemistry on the surface.

Triton

Neptune's giant moon orbits backward, opposite the direction of the planet's rotation, probably because it was captured when it passed too close millions of years ago. That wrenching event must have melted its icy interior; Triton is -390°F on the surface but might still have a warm, wet layer near its core.

Titan

Saturn's largest moon has a thick, methane-tinged atmosphere and lakes of liquid hydrocarbons, which could support a version of the organic chemistry that preceded life on our planet. Temperatures here are too low for any known kind of biology, although asteroid impacts might create temporary oases...and life is full of surprises.

Ganymede

Orbiting Jupiter just beyond Europa, the giant moon Ganymede—bigger than the planet Mercury—looks rather inert on the outside, but it may be warm and active within. The European JUICE mission, set for launch in 2022, will reveal more about Ganymede's makeup, and will carry out studies of Europa, too.

Pluto

Life on Pluto? Not as crazy as it sounds. Long ago, Pluto was energized by a giant impact that created its moon Charon, and it probably melted in the process. There could still be an aquifer of some sort locked away inside. The *New Horizons* probe will fly past Pluto in July, carrying seven instruments to scrutinize the dwarf planet.

had to be due to biology," Nealson says. He suspected bacteria in the lake were getting rid of the manganese oxide almost as quickly as it formed. That theory made perfect sense, but it ran counter to the textbook wisdom: that microbes cannot break down a raw piece of metal any more than you or I can. The mystery kept itching at him. In 1985, Nealson relocated to the University of Wisconsin-Milwaukee, and began research at Oneida Lake to prove his hunch correct.

After a two-year search, Nealson succeeded in identifying the manganese thief: *Shewanella*, a bacterium that functioned unlike any he had ever known. "As soon as I saw what *Shewanella* could do, I just went wacky," Nealson says. "I called all my students into the lab and I said, 'This is a very, very important organism to understand. Nobody's going to believe it. It's going to take us 10 or 15 years to convince the world it's true.'"

For most living, air-breathing creatures, Nealson says, "The glucose that we eat supplies the electrons, the oxygen we breathe receives the electrons, and that electron flow is what runs our bodies." That's basic metabolism. The challenge for every organism is finding both sources of electrons and places to discard them in order to complete the circuit. *Shewanella* consumes electrons from carbohydrates, but it sheds them in an unusual way: "It swims up to the metal oxide and respires it," Nealson says. "We call this 'breathing rocks.'" Here is where the scientific heresies begin.

Shewanella's outer membrane is full of tiny chemical wires, enabled by specialized proteins, that let it move electricity out of the cell. The wires make direct contact with the manganese oxide, which is how it can deposit electrons and "breathe" a solid substance. Furthermore, Nealson realized that the bacterium doesn't even care whether the substance on the outside of its membrane is manganese oxide or something else entirely, so long as it will complete the electric circuit.

While Nealson and his team were gathering proof that *Shewanella* is as extraordinary as it seemed, another microbiologist made a similar discovery. Derek Lovley, then a project chief at the U.S. Geological Survey, found an electron-moving bacterium, *Geobacter*,

living on the bottom of the Potomac River. “*Geobacter*’s proteins have a completely different evolutionary origin, but they solve the problem the same way,” Nealson says. Finding two unrelated microbes with an affinity for raw electricity provided reassuring evidence that *Shewanella* wasn’t some one-off weirdo.

At this point, Nealson realized the microbial landscape of the planet might be different than anyone had thought. He also realized he had probably only just begun to explore what electric bacteria are capable of.

ANNETTE ROWE, A POSTDOC researcher in Nealson’s group, is currently speeding through life’s outer limits in the lab across the hall from where I was talking with Nealson. There are fish tanks, test tubes, wires, incubators, and anaerobic chambers with push-through working gloves that look like old set pieces from *CSI*. I pass a large tank of slow-stirring liquid, with a family of *Shewanella* growing inside. (“Yeah, too bad you can’t see them,” Rowe says apologetically.) Motivational photos of Nealson gaze down from tall shelving racks. Sample captions: “I AM WATCHING YOU” and “GET YOUR ASS TO WORK.”

The place looks vaguely like an aquarium for microbes, and in fact that’s pretty much what it is. Just as Nealson found *Shewanella* in Oneida Lake, Rowe and her collaborators have been scouting local marine settings for other electric bacteria, the stranger the better, then cultivating them and trying to figure out what makes them tick.

“We’ve been working in Catalina Harbor. They have a really nice study system out there,” she says. Rowe has the slightly weary look of a graduate student who pulls a lot of late hours, but she lights up when she talks about getting into the field. “Basically, we pull up sediment and sieve it to get rid of invertebrates, and get a nice well-mixed system at the same time. We set up 10-gallon aquariums full of this sediment and bury electrodes in it. And then we look for signs of bacterial colonization.”

The electrode is the key to attracting the type of bacteria Rowe is looking for: not the kind that dumps electrons onto minerals, but the kind that scavenges

Nealson realized the microbial landscape of the planet might be different than anyone had thought. He also realized he had only begun to explore what electric bacteria are capable of.

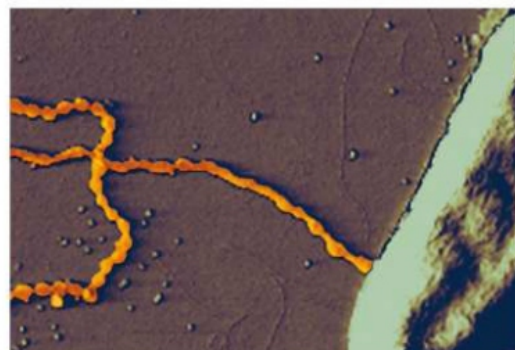
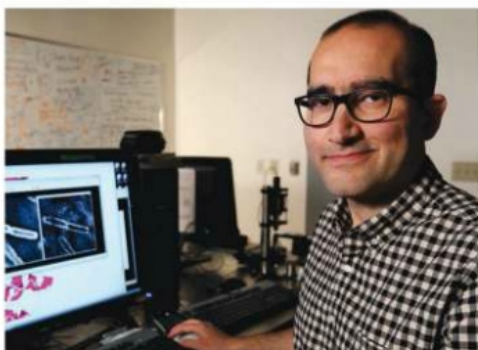
electrons from them. Not breathers, but eaters. To those bacteria, a cathode looks like one enormous, electrically charged dinner table. Rowe adjusts the electric potential to mimic compounds the organisms might normally draw their energy from, and they swim right up.

As Rowe began sorting through her tanks of sedimentary muck, she was struck by the sheer diversity of bacteria she’d collected. “I’ve isolated a whole slew of electrode-oxidizing bugs,” she

energy from them. But they do okay.”

Another discovery is even more astonishing. Six of Rowe’s new bacterial strains can live on electrons alone. “It’s a crazy phenomenon,” she says, one that is well beyond anything Nealson had discovered up to now. “I’ve kept some of these bugs for over a month with no addition of carbon,” she says. They must be subsisting solely on electricity from the electrode, because there is nothing else.

These microbes are the ones that



Moh El-Naggar showed that *Shewanella*’s nanowires are an extension of its cell membrane and can conduct electricity to complete a circuit.

says—roughly a thousand strains in total. So far, she’s identified 30 of them, all previously unknown.

One important lesson that has emerged from Rowe’s work is that bacteria have a wide variety of mechanisms for moving electrons around. That finding suggests the ability evolved multiple times. Even more surprising, some of the bacteria, including *Shewanella*, can swing both ways. “A lot of organisms that can put electrons onto an electrode can also do the opposite and take electrons from one”—though not at the same time—Rowe says. That ability to reverse course surprises me, and Rowe, too. “I’d think it would be really hard on the organisms. You’re basically stealing

had Nealson so worked up in our earlier conversation. They are not just new to science; they require an entirely new method of collection and culture. The vast majority of Rowe’s strains must be grown on a cathode, not in a petri dish. And they indicate an immense and largely alien ecosystem here on Earth. The National Science Foundation calls it the “dark energy biosphere” and is funding Rowe to learn more about this parallel microbial universe.

To Nealson, his protégé’s breakthrough both validates and stomps all over his own revelations about how life works: “I’ve been doing microbiology for 45 years,” he says. “It’s just wild to have your whole view change so drastically.”

AS STAGGERING AS ROWE'S findings are, there is a certain level of intellectual remoteness to all that talk about electrons and energy levels. No matter how much I stare into the flask, I still keep wishing I could see what the bacteria are doing with my own eyes. That frustration dissipates when I stop in on Moh El-Naggar, who works a couple buildings over on the USC campus. He has actual videos of the microbes in action, unspooling wires and setting up microscopic electrical grids.

El-Naggar's bacterial video project began as an effort to disprove a theory. Experiments Neelson had done with *Shewanella* showed that the bacteria can make contact with a metallic surface to deposit electrons. Other studies had revealed that bacteria sometimes produce hairlike appendages of unknown function. Some researchers dismissed those growths as unimportant, but a few wondered whether the hairs were actually "nanowires" created by the bacteria to move electrons.

To El-Naggar, that reasoning seemed too tidy: "I kind of went into it thinking, it can't really work that way, right? I'm going to do the measurements that show it doesn't." So El-Naggar did what any good home handyman would. He clipped a couple leads onto the wires to see if they conduct electricity. They do. Then he checked to see if the circuit is live, with current flowing across the wires. It is. Finally, he monitored the wires as they form, recording the cells lighting up with activity once they complete a circuit.

Afterward, he had a series of mind-boggling movies in which you can watch *Shewanella* reach out to an electrode in search of a place to deposit electrons. Sometimes the bacteria will link up with one another, possibly fobbing off electrons on cells that are able to accept them. El-Naggar describes the shock that runs through the room when he shows his videos at conferences: "You're sitting there in the dark, you start the movie, and then you hear, 'Ahh! Cool!'"

Nanowires may be related to yet another widespread but newly discovered bacterial talent, the ability to connect into sausage-link cables thousands of cells long. As yet there is no indication whether Rowe's electric bacteria form

...AND HOW TO FIND IT

So you've got a promising space rock. Now what? —CSP

1 TEST FOR METABOLIC ACTIVITY

The first serious attempt to find alien life took place in 1976, when the twin *Viking* probes sought out organisms by mixing Martian soil with nutrients and radioactive carbon. The results were negative (you probably knew that), but clouded by the complex soil chemistry.

2 FOLLOW THE WATER

NASA's current Mars research, led by the \$2.5 billion *Curiosity* rover, focuses on learning whether the planet once had a warm, wet environment. Studies of Gale Crater look encouraging; unfortunately, these efforts show only that Mars *could* have sustained life, not that it actually *did*.

3 SCAN FOR ORGANICS

Taking lessons from *Viking* and *Curiosity*, NASA's upcoming *Mars2020* rover will include two instruments that scan the environment for signs of organic compounds. This technique can cover a lot of ground, and does not make specific assumptions about the metabolism of Mars life.

4 LOOK FOR CHEMICAL ORGANIZATION

Another approach would be to seek out chemical patterns suggestive of biological activity. For example, DNA is full of repeating molecular motifs. More subtly, there are almost no natural nitrogen-bearing minerals, so an array of nitrogen compounds would raise a red flag.

5 MEASURE ELECTRIC POTENTIAL

All life manipulates electrical energy. If the electric potential in the ground drops steadily with depth (as happens on Earth), that could indicate successive populations of microbes are pulling electrons from the environment. It would be a low-key First Contact, but revolutionary all the same.

these kinds of cables (the research is far too new), but studies at Aarhus University in Denmark indicate that such cables do support a flow of electrons. El-Naggar speculates that the cables are like drinking straws, allowing bacteria buried deep in sediment to breathe from the top of the pile by pushing electrons up through the tube, from one cell to the next.

Just a few years ago, nobody imagined that any bacteria were capable of such behaviors. Now El-Naggar suspects that nanowires and cables are used widely by bacteria, and not just among the most extreme electron-eaters. He is collaborating with colleagues in the dental school at USC to examine evidence of nanowires in the bacterial films that form in people's mouths; cell-to-cell electrical linkages might in fact be a general characteristic of biofilms, bacterial collectives, both benign and pathogenic, that take up residence on a surface.

Shelley Minteer, an electrochemist at the University of Utah, has probed even deeper into cell biology. She discovered that mitochondria—the power-generating units inside the cells of all complex cellular organisms, including humans—can interact electrically with surfaces outside themselves. That fits with a well-accepted theory that mitochondria evolved as free-living bacteria that later merged with other cells, forming a permanent partnership. Even after a billion years, mitochondria may retain some of the capabilities they had in their days of independence. It is possible, then, that we all have a smidge of electric alien behavior locked away inside us.

MY FIRST TRIP FROM NEALSON'S office took me across the hall. My last trip takes me to Mars. Not such a big leap, actually: Nealson has never made a clean philosophical distinction between the search for exotic life on Earth and the search for life on other planets. For several years he worked at NASA's Jet Propulsion Lab (JPL), where he set up the astrobiology group. Now the ideas he developed there will get a formal test aboard the upcoming *Mars2020* rover.

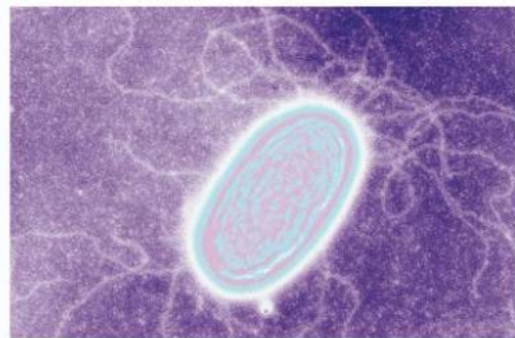
In some ways, getting to Mars is a cakewalk compared to the challenge of knowing what to search for once you arrive. The Viking missions in the 1970s

They are alien not just in what they do but in how they do it. Their Earth seems to be a world built on cooperation, a far cry from the more familiar one of cutthroat competition.

landed just fine but got tripped up by things that smelled like life. The scientists studying the infamous Mars meteorite in the 1990s may have been led astray by things that looked like life. And the fancy new *Curiosity* rover has found intriguing whiffs of methane, but their connection to biology is utterly unknown. That's what Nealson's team grappled with at JPL. "Could you really figure out what the universal properties of any life must be? It's very hard to solve this problem, because we can't get away from our own biases," he says.

tations are responses to extreme environments. Scrounging for electrons and sprouting nanowires are strategies for surviving when there is not enough food to do much growing and competing—just enough to help an organism hunker down and keep the flame of life lit. Such conditions are common in deep ocean sediments and far underground. If life exists on Mars and other worlds (Europa? Titan?), there's a good chance that it, too, is huddled in resource-constrained settings far beneath the surface.

While NASA gears up for *MARS2020*,



Because *Geobacter metallireducens* can eat waste and produce electricity, the bacteria could prove useful in microbial fuel cells.

SHERLOC is part of the answer. It is one of seven science instruments aboard *Mars2020*. One of Nealson's former JPL employees, Rohit Bhartia, was a lead designer, and the instrument is heavily informed by the lessons of metal-breathing bacteria. *Shewanella* expanded scientists' understanding of metabolism, and so SHERLOC will be looking for a wider spectrum of possible biosignatures. It will zap targets with ultraviolet rays and look for visual effects that indicate certain organic compounds and minerals.

Although SHERLOC will not be searching for life per se—only for the trail it leaves behind—electric bacteria suggest new ways to find active alien biology as well. All of the electric adap-

Rowe and others in the USC group are bioprospecting for more electric bacteria here on Earth, relocating their operation from the shallow waters around Catalina Island to deep boreholes in the Mojave desert and mines in South Dakota. These sites could not only expose more of Earth's hidden biodiversity; they could also help guide thinking about possible alien biologies. "When we go to other planets, we look for life on the surface, but really there's so much energy in the subsurface," Nealson says. "I'll be astounded if this extracellular electron transport isn't the rule there."

In the process of poking electrodes into different environments and rounding up electric microbes, Nealson's team

has noted a distinctive pattern: Stick a spike in the ground pretty much anywhere on Earth, and you can measure the electric potential steadily dropping off the deeper you go. That's because microbes at each depth are chasing after whatever electrons are available. The most energetic organisms, using the most energetic reactions, live up top, where resources are the most abundant. The farther you go into the regions of scarcity, the more life has to grab at any energy it can get.

That electric gradient sure sounds like another good candidate for a universal signifier of life. "If there isn't life, there shouldn't be gradients," Neilson says. So instead of running complicated chemical experiments that might miss some unfamiliar type of biological activity, he muses, why not stick a giant probe in Mars and replicate Rowe's microbe hunting expeditions in Catalina? He envisions a whole flock of javelin-like probes that drop from an orbiter and penetrate the ground all around the planet. Each one would have a little transponder to send data up to the science satellites already circling the Red Planet. The probes would look for electrical gradients, flagging possible locations of biological activity for closer study. NASA and Russia have attempted simpler Mars penetrators, though both missions failed. Now the nonprofit Explore Mars is trying to raise funds for an "ExoLance" to seek subsurface life there.

Neilson is on a roll, so I goad him on: Could you do the same thing on Europa? He slows down for only a beat. "Europa is tough, because it's all ice. . . . You would imagine that you would put something on the surface with a solar panel or a radioactive generator and just melt your way down in with the probe. You could radiation-harden just the little thing above the electronics."

If they find no signs of electric biology, the probes could still measure geochemistry beneath the surface, which is valuable in and of itself. And if they do find it, popping champagne corks would be premature: You'd want to see if it is dynamic, changing with daylight or temperatures, for instance. That kind of additional signal would be strong circumstantial evidence of life. It still wouldn't be the definitive discovery of **continued on page 70**

EXTREME BIOLOGY



Dead Sea Bacteria

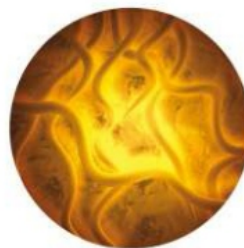
The Dead Sea is so saline that it's nearly devoid of life—but not completely. Researchers found microbial mats living near the lake's freshwater vents. Unlike other salt-loving organisms, they live in a constant state of flux between salty and freshwater. "Now we understand there could be organisms not restricted to a single extreme environment," says Danny Ionescu, a marine microbiologist for the Leibniz Institute for Freshwater Ecology and Inland Fisheries in Germany.



Blobfish

The blobfish is best known for being voted "the world's ugliest animal" by the Ugly Animal Preservation Society, but its gelatinous form is notable for another reason: It enables the fish to inhabit waters thousands of feet deep off the coast of Australia, where pressure is several dozen times higher than at sea level. Because a swim bladder would be ineffective at such depths, the blobfish uses its whole jelly-like body for buoyancy.

Some of the best evidence for life in space lives right here on Earth: It's weird, adaptable, and far harder than we ever thought. —ALISSA ZHU



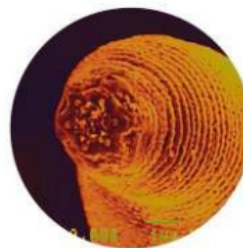
Lyme Disease Bacteria

The bacterium that causes Lyme Disease is the only known organism that doesn't need iron for its basic life chemistry. Instead, *Borrelia burgdorferi* uses manganese and other minerals. Johns Hopkins University microbiologist Valeria Culotta says that makes our defense against the infection virtually futile: "When the immune system tries to starve it of iron, it says, 'I don't care. You can make yourself as anemic as you want but it won't affect me.'"



Tardigrade

In an experiment in 2007, tardigrades became the first multicelled creatures to be exposed to the vacuum of space and live. They can withstand temperatures barely above absolute zero, pressure exceeding that in the deepest ocean trenches, and deadly levels of radiation. They have no skeletal or circulatory systems, and no one knows how long they can survive: Tardigrades delay death by moving in and out of cryptobiosis—essentially, suspended animation.



Devil Worm

We've long known some bacteria can withstand the intense heat and crushing pressure miles below the Earth's surface, but the apex predator of this subterranean foodchain was a surprising find: The devil worm can survive more than two miles underground. "Nematodes have been around long before we appeared on the planet," says Gaetan Borgonie, a zoologist at the Extreme Life Isyensya research institute in Belgium, "and they will easily outlast us."



Deep-Sea Shrimp

Along deep-sea hydrothermal vents in the Caribbean, in an ecosystem totally devoid of sunlight, a species of shrimp called *Rimicaris hybisae* thrives by coexisting with chemosynthetic bacteria. "That makes them analogous with organisms potentially living in Europa," says Max Coleman, an astrobiologist studying them for NASA. The bacteria colonize the crustaceans' specially adapted gill covers and use hydrogen sulfide to produce organic matter for the shrimp to eat.

INSTRUCTIONS NOT INCLUDED



WHAT DOES THE DISAPPEARANCE OF
THE COMMON MANUAL SAY ABOUT US?



By
Mark
Svenvold

ILLUSTRATION BY
ANDERSON
NEWTON DESIGN

In the late 17th century, the printer Joseph Moxon published *Mechanick Exercises*, the first guide to printing in any language. It had been nearly 240 years since the debut of Gutenberg's press, and books had proliferated. There were Bibles, of course, along with lots of schlocky literature, some porn, and guides to everyday topics—how to polish jewels, how to cast a spell against your enemy. But Moxon's manual was subtly different. It rang with a decidedly DIY tone and suggested that readers could learn a new trade, at home, in their spare time.



To someone in 17th-century Europe, this was a deeply subversive notion. From the fall of the Roman Empire to the dawn of the Renaissance, age-old social hierarchies held firm. You were born into a station, whether peasantry or trade work or aristocracy, and you and your family remained there for generations. But then came science

and technology, and with them new trades and opportunities. With no established guild system in place for many of these new professions (printer, navigator, and so on), readers could, with the help of a manual, circumvent years of apprenticeship and change the course of their lives, at least in theory.

Mechanick Exercises was not

the first manual. Vitruvius's *Ten Books on Architecture* is one of the only true manuals to survive from antiquity. It offers clear and concise instructions for how and where to construct a house (not in a dell, for instance), where to orient your summer and winter rooms, and many other useful matters. Scribes in the Middle Ages produced their share of guides too. One of the most consistently produced titles in the entire history of writing, the 15th-century *Aristotle's Masterpiece*, is a sex manual. But where those early books served as compendia of sorts—the compiled wisdom on any given subject—Moxon's manual and others like it promised something more: systematic treatments for solving complex problems, such as how to lift a horse with your little pinkie (and a pulley system), how to survey land or build fortifications. These were books filled with ingenious methods, and they offered something new and relatively democratic: agency, skill, and command for anyone who could read.

And so it went. As manuals explained increasingly complex systems, they grew in size, developing into the heavy, barely penetrable and largely unread books that most people think of today. But then in the 1980s, the manual began to change. Instead of growing, it began to shrink and even disappear. Instead of mastery, it promised competence. My new iPhone, for instance, came with a "manual" that was about as brief as a Christmas card (and I did not read it). A recent rental car did not come with a manual at all, making its nonreading a snap (but finding out how to pop the trunk rather difficult).

The manuals of old, it turns out, have shape-shifted inward, into the devices themselves. That, or their information has been off-loaded to help-desk support or a parallel, Internet FAQ universe: a searchable realm often filled with answers to almost every question but the one you are asking. Change is the way of the universe,

but what does it say that most of us now live our lives using tools that are, practically speaking, beyond our understanding or ability to fix? Have we traded away something important, perhaps even defining, about ourselves—a sense of our own autonomy and control over our tools—for the dubious benefit of convenience?

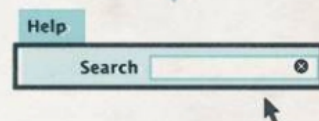
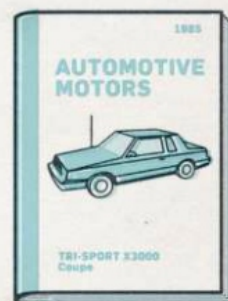
The Man Who Killed the Manual

If the era of minimalist manual design in which we live could be traced back to one person, it would be John Carroll. In 1976, Carroll, a linguistic psychologist, was finishing his Ph.D. at Columbia University and took a job at IBM's Watson Research Center in Yorktown Heights, New York. His job was to help make computer programmers more efficient, but that quickly changed to a new focus—making computers more usable for average people. That was a big shift in thinking. "You have to remember," Carroll says, "IBM was probably the richest computer research facility in the world, but at the time, the idea of focusing on the average everyday user was sort of off the radar."

Carroll was doing, in essence, dissident research. He set up a lab, gave secretaries computers and manuals, and then studied them as they tried to accomplish regular office tasks. He tracked "frustration episodes," observing as subjects became progressively more flummoxed by their manuals. "People would look at me, shaking, and they'd say, 'I can't do this.' And then they'd get up and put their coat on. One person literally had to flee the building," he says.

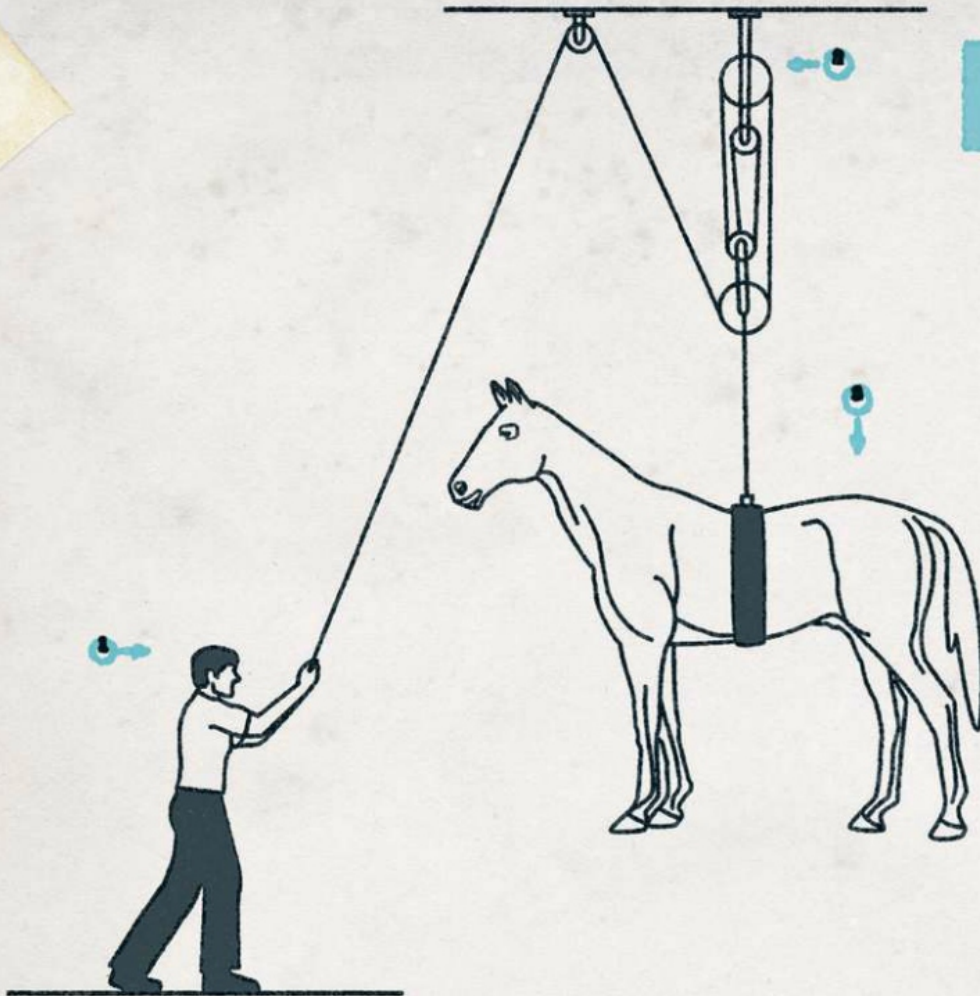
Though Carroll had worked at IBM for more than a decade, his quiet revolution—a culture-wide shift not just in the shape of manuals but in how we learn to use technology—didn't coalesce until one day while he was on a vacation in Germany. He had just finished a manuscript that would become his groundbreaking minimalist opus, but he had no

These books, filled with ingenious methods, offered something new and relatively democratic: agency, skill, and command for anyone who could read.



Over the centuries, manuals have evolved to reflect our shifting relationship with technology.

FIG. 1 - LIFTING HORSE WITH PULLEY



active engagement. Short, succinct manuals allow the user to dive into many different tasks and to accomplish them quickly, thereby gaining a sense of control and autonomy that inspires further learning. "Skeptics would say we weren't providing the user with any theoretical foundation," Carroll says, "but we found that people got through their initial learning faster, and that later on, when they needed to learn more complex tasks, the users were also better at doing that, too."

Manual as Mirror

So manuals began to slip from view. They still exist, sure. Highly complex things, like jet planes or nuclear plants, rely on big integrated enterprise resource planning systems, into which an army of sensors and engineers log the status and service history of every part in order to maintain standards. Many think that BP's failure, in effect, to update the manual of the Deepwater Horizon oil rig led to the spill in the Gulf. But for most consumer products, the

title for it. Then, in the basement of a castle in Nurnberg, he saw a postcard of a painting depicting an old German folktale: two professorial-looking gentlemen in a library standing over a young student who had a funnel affixed to the top of his head. The teachers are busily choosing potions from the library shelves and pouring knowledge down the funnel and into the boy. For Carroll, the image clearly represented the dominant paradigm in most scientific fields—the "systems approach," a way of dividing the world into taxonomic orders and protocols of action. In computer science, that meant learning an arcane and exacting "command language" and typing directives precisely as prescribed by the system. Carroll's book, *The Nurnberg Funnel*, outlined a new philosophy. Instead of focusing on the needs and values of the system designers, it shifted attention onto the end-user, the secretary in the office who needs to hyphenate a compound word.

Steve Jobs and Steve Wozniak, among others, quickly adopted a similar approach and more would soon follow. Writing a manual from a minimalist point of view, Carroll says, proved enormously successful because it harnessed the true source of all learning—



Psychologist John Carroll shifted the focus of the manual from engineers to end users—and changed how we interact with gadgets forever.

The manual has become less an object or thing and more a verb, a service, a response to the statement most likely uttered by someone stymied by a gadget: Help.

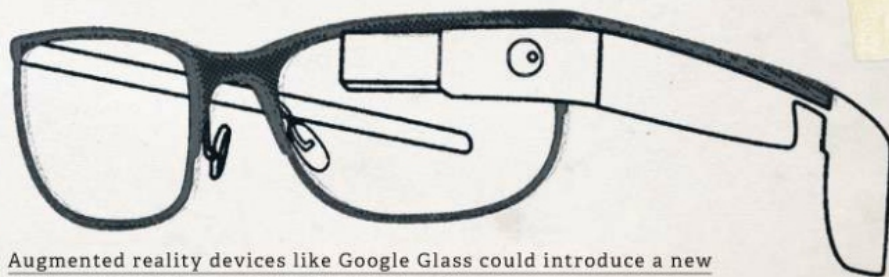
manual has become less an object or a thing and more a verb, a service, a response to the statement most likely uttered (or yelled at the top of one's lungs) by someone stymied by a gadget: Help.

According to Carroll, the help we once sought from a manual is now mostly embedded into the apps we use every day. It could also be crowdsourced, with users contributing Q&As or uploading how-to videos to YouTube, or it could be programmed into a weak artificial intelligence such as Siri or Cortana. Help can even be predictive, tracking our keystrokes or vocal cues to steer us away from trouble before we find it. Xerox is already using predictive analytics to manage calls from Medicare and Medicaid recipients more effectively. And IBM's Watson Engagement Advisor, part of a new generation of cognitive assistants, can analyze large sets of customer service problems to more efficiently answer (or even anticipate) problems during a purchase. Help may soon arrive in the form of augmented reality. Carroll suggests that technology like Google Glass might one day offer a "task intelligence" visual overlay to help users figure out objects in their field of view.

For most of us, the transition from physical manuals to embedded help has been slow, steady, and apparently benign, like the proverbial tide that lifts all boats—who would argue against help after all? The disappearance of the manual-as-book coincides, moreover, with documented realities about how people actually learn to use new tools and devices. Studies published by the Society for Technical Communication, which regularly reports on "human-machine interaction," suggest that even when manuals are available, people tend not to read or use them.

Yet even as we gladly cede more and more control of our tools, a growing chorus is calling attention to the costs. In his book *Who Owns the Future?*, computer scientist and virtual reality pioneer Jaron Lanier uses the analogy of the Sirens from Homer's *Odyssey*. The creatures would lull sailors into complacency with

their beautiful songs, only to have their boats wreck on the rocks. Lured by the convenience of the Internet, search engines, and all that they promise, most consumers are, in Lanier's estimation, similar to those doomed sailors: a little too ready to give "the sirens control of the interaction." Kimberly Nasief, president and co-founder of Measure Consumer Perspectives, a consumer monitoring and customer service consultancy based in Louisville, Kentucky, wrote about how Apple's ease-of-use might be making her a dumber user. She tried out an Android tablet, and the greater



Augmented reality devices like Google Glass could introduce a new form of interactive manual into the world.

complexity of the operating system actually forced her to learn more: "It made me develop some critical thinking on how the system I was using worked. With Apple, I don't have to do that. It does it for me. And that just might be dangerous. Dangerous in that if I no longer am learning, or if it's done for me, then I might just get technologically left behind," she wrote.

Today the hazards of being left behind seem ever more real. Even Carroll notes that research has suggested an unforeseen consequence of the minimalist approach. Furnished only with a manual of one or two pages, users soon reach a comfort zone, a knowledge plateau from which they tend not to wander. The aggregate effect, culturally, may be that less is less. The less we're inclined to know about our devices, the more beholden we are to the manufacturers that make them, and the more we offer control to those who, for good or for ill, know more than we do. If manuals began as great equalizers, then their disappearance should at least give us pause. By dispensing with them, we could, consciously or no, be setting the stage for something few would relish: a society divided. **Ps**

THE WORST JOBS^{IN} SCIENCE

By Bob Parks / Illustrations by Peter and Maria Hoey

Think your job's bad? Try excavating 4,500 years of bat guano. These 10 down-and-dirty labors are hard, dangerous, and outright gross—and people love them anyway.



FISH GUTTER

Crisp sea air isn't a match for the stink of stomach juices and half-digested squid, but marine biologist Michelle Staudinger doesn't mind. When boats come in from fishing tournaments up and down the East Coast, she's waiting on the docks, asking anglers to let her clean their catch for free in exchange

"I GET A LOT OF COMPLIMENTS ON HOW FAST I CAN GUT A TUNA."

for the stomach contents. On any given weekend, she says, "I'm usually elbow-deep into one or another of the East Coast's pelagic fishes. I get a lot of compliments on how fast I can gut a tuna."

At University of Massachusetts Amherst, Staudinger surveys coastal fish and marine mammals to evaluate the predator-prey relationship over time. Besides relying on fishermen to deliver species that live far offshore, she waits for some animals, such





Worst Jobs

as dwarf sperm whales, to wash up dead. She once necropsied a whale that had been shipped on a flatbed truck from Florida to Massachusetts. "Oh, yeah, it's disgusting," she says. "But we now have baseline data for looking at how ecology is changing as the impacts of climate change grow."



SOBRIETY TESTER

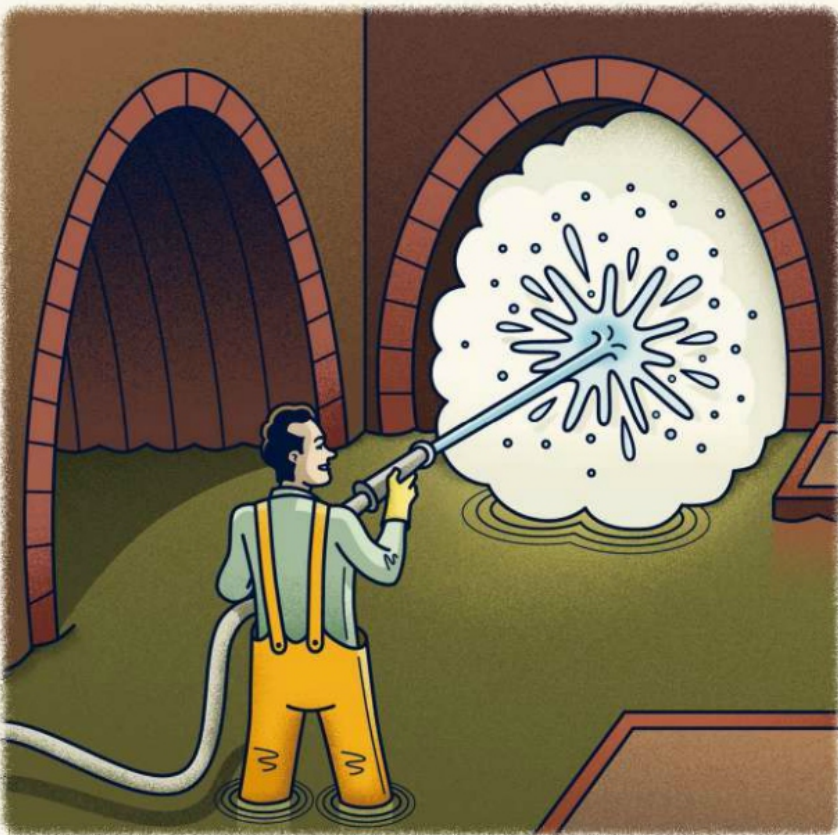
Can people accurately estimate their own blood alcohol level when inebriated? That's the question Loyola Marymount University researchers set out to answer. To get data, they sent then-psychology student Greg Wisenberg into frat parties and late-night pizza places near various southern California universities. Once there, he had to quiz revelers on their blood alcohol level and actually measure it with a breathalyzer. Not surprisingly, reactions around the kegs were mixed. "People were suspicious," Wisenberg says. "Like, 'What are you doing here? Why aren't you drunk too?'"

The results showed that drinkers fall into two groups: Those who were slightly buzzed consistently overestimated their intoxication, while those who were loaded grossly underestimated it. If the researchers can elucidate how partiers perceive inebriation, others could use the information to teach safety and intervention. A noble goal, but cold comfort for Wisenberg, who suffered insults and even half-serious physical threats. To one particularly boisterous group, he had to say, "I'm working now. I'm not going to fight you, but you can take my survey!"

FATBERG FLUSHER

Few people know that the food waste they pour down their drains can turn into fatbergs—hideous, multi-ton globs of coagulated fat that can grow as long as a 747. London's sewer company deals with 55,000 a year that can obstruct passages and causing flooding. That's why Dan Brackley leads a team of 38 people to clear bergs with high-pressure water jets, shovels, and a large chainsaw-like machine. The job isn't just disgusting,

it's also dangerous: "The fatberg eats oxygen out of the air and gives off heat and high levels of methane," Brackley says. He wears sparkproof tungsten-studded waders, a portable methane and hydrogen sulfide alarm, an emergency rebreather, and a total-body Tyvek suit (fortunately, he's fallen only once.) Still, he says, "The smell gets into my pores even after two or three showers. You have to rub down with sugar soap."





DEAD SEA SAMPLER

As John Selker began installing sensors in the Dead Sea, a tourist perished after taking a gulp of water. "It turns out the salt is so intensely concentrated that it's hazardous," says Selker, a hydrological engineer at Oregon State University.

The infamous lake is covered with a thick, highly saline layer of 97°F water, and it's getting saltier as it evaporates. Selker's task was to figure out whether the surface exchanges water with the cooler layer far below. He eventually found that it does—information that could be used to better manage the lake. But first he learned a different lesson: Anything left in the Dead Sea eventually grows heavy with salt and sinks.

After Selker began deploying more than a million dollars worth of fiber-optic cable, his computer-powered buoy foundered to the bottom. Then his team had to face the treacherous task of recovering it. "I was scared," he says. "This is a fluid that burns like acid if you get it in your eyes. We had no life preservers, we were standing on little planks over the surface, and a helicopter was flying in to the beach to take away the dead guy."



QUEASINESS GENERATOR

Former Greek Navy officer Panagiotis Matsangas got his Ph.D. in nausea. Now a scientist for the Naval Postgraduate School in Monterey, California, his job is to convince test subjects to sit in a special motorized chair that heaves side to side for an hour, while they try to solve cognitive tests through virtual-reality goggles. "People

"I WAS SCARED. THIS IS A FLUID THAT BURNS LIKE ACID IF YOU GET IT IN YOUR EYES."

often don't want to participate when they learn too much about my studies beforehand," Matsangas says.

Inducing even mild motion sickness, he's found, causes a person's multitasking ability and cognitive performance to fall, which could impact everything from Navy staffing policies to ship design. But when Matsangas tries to butter up subjects by explaining the importance of the tests, it doesn't always work, he says. "Some of them feel really unwell."



TROLL HUNTER

If you've ever had a little too much fun editing Wikipedia, you may have been part of information scientist Madelyn Rose Sanfilippo's research. Whoever changed Grover Cleveland's page to say he had "mad beat boxing skills" is an example of the light-hearted form of trolling Sanfilippo researches. But her work at Indiana University has also sent Sanfilippo into the ugliest corners of the Internet. People will join

memorial pages for the deceased, for example, just to mock the public mourning. "You can't really sit there and

read for extensive periods of time because it becomes overwhelming," Sanfilippo says.

There's also a professional hazard to maintaining close proximity with trolls, who see an information scientist as bait—she often receives insulting and offensive emails. "It's mostly poking fun at my credibility as a researcher," says Sanfilippo. Despite the harassment, she thinks the work is only getting more important. "With trolling's increasing prevalence," she says, "it's important to understand how to mitigate the impacts."

WRIGGLING WITH PARASITES

Christopher Schmitt, a primatologist at the University of California, Berkeley, is currently researching the role of genomics in primates' weight gain.



I was studying wild lowland woolly monkeys in Amazonian Ecuador, and one day I was running in a downpour when I accidentally fell down on a trail and stuck my hand in some jaguar scat. Then I made the mistake of scratching some old tick bites, introducing a type of hookworm. These worms don't have the enzymes to digest the dermis and enter the bloodstream, so they crawl around under the skin leaving raised trails. They itched so bad, it felt

like my bones were on fire. A few weeks later, in an effort to help, a Quechua guide had me grind up leaves, spit in them, and rub the paste on my skin. The next morning, I woke up with black chemical burns all over. Finally, I went five hours by boat and truck to the closest medical facility to get a simple anti-parasitic medicine. But it was worth it. Because of that trip, I was able to publish an important paper about monkeys' social groupings."

Worst Jobs

What's the worst job you've ever had?

For all I've done, I really hated selling magazines over the phone to get through college. For whatever reason, I was good at it, and it paid me a lot of money. But I learned that just because you are good at something doesn't mean you should do it. If you're going to be happy, you need to separate your passions from your results.

What's the most important thing you learned from doing dirty jobs?

The realization it has to be done. For example, when we were replacing wooden water tanks on the roofs of buildings in Manhattan—you're way up in the air and you're pulling apart the very thing you're standing on. You're on a beam swinging a sledgehammer all day long. But the guys in the crew, they don't look at themselves as construction workers doing manual labor; they look at it as a job that allows eight million people to have water. They see themselves as lifesavers.

Do other people see them that way?

Well, it's a problem that the skilled trades don't get a lot of love. We currently find ourselves as a country with one trillion dollars in student loans and three million available jobs that require skill but not a four-year degree. There are a lot of kids with college degrees in their parents' basements, completely educated but totally untrained for the jobs that exist.

What attracts people to jobs that few others find appealing?

When I was going out to a shark autopsy, I thought I'd meet people who felt they had drawn the short straw. But again and again, we found people who so loved the challenge and the stink and the grime—and took huge pride in the fact that they were doing something the average person wouldn't want to do. They're usually into it up to their elbows, and at the end of the day, they can see progress in a way that people in other vocations don't.

Do you hope there's something to gain from exploring the world of weird work?

Personally, I don't think there is such a thing as a good job or a bad job. Part of this country's problem right now is that people approach work this way. To be happy, you think you have to get one of the good jobs, and the minute you start operating with that assumption, you've just narrowed your possibilities for happiness by a lot. That's really the big lesson.

HOW TO TAKE PRIDE IN A SHARK AUTOPSY

AND OTHER LESSONS FROM MIKE ROWE



As the longtime host of the show *Dirty Jobs*, Mike Rowe tried out hundreds of distasteful tasks. Now he's got a new job himself: Each week on CNN's *Somebody's Gotta Do It*, he seeks out people passionate about weird work. Rowe, in other words, knows a thing or two about why someone would toil at labors no one else wants.



"If you're going to be happy, you need to separate your passions from your results."



ROBOT TEACHER

Scientists have long sought to create the ultimate social robot, a personable machine like C-3PO. But for artificial intelligence to react to our emotions, someone's first got to train bots to recognize them—which is Michel Valstar's job. A computer scientist at the University of Nottingham in England, Valstar spends his days creating a database of faces showing anger, disgust, fear, and happiness. "Computers are so literal," he says. "They have to be fed every possible situation and taught the context."

First, Valstar recruits human subjects to make expressions for a camera. To capture real anguish, for example, he asked a group of chronic back pain sufferers to repeatedly perform difficult stretches. Then he annotates the footage, a task that takes several hours per minute of video. "It's the kind of work that turns you into a zombie," he says, requiring close attention to detail but promising endless monotony. With the help of buckets of coffee, Valstar has now built a record so comprehensive it will be used in the new field of behaviomedics—training robots to spot changes in patients caused by medical conditions like pain or depression.

RAT EXERCISER

After graduate school, Marc Kubasak set an ambitious goal: Find a way for paralyzed people to walk. But to help people, first he had to help rats. Kubasak took paralyzed animals, transplanted glial cells from the olfactory bulb in the brain to the injured area, and then re-trained them to walk. That involved sewing little vests to suspend the rodents from a robotic arm. Then, he says, "I had to make little circles with my fingers moving the rats' legs on a treadmill for five to 12 hours a day, five days a week." He walked 40 rats, clocking 2,500 hours

over the course of a year.

In the middle of the study, Kubasak developed a rodent allergy: His airways closed up and his hand swelled to the size of a catcher's mitt. He was rushed to the ER. Eventually, he had to work in a total-body suit, complete with battery-powered respirator. But Kubasak persevered. Most of his rats walked again. And this year, doctors at Wrocław Medical University in Poland and University College London translated Kubasak's procedure to a man whose spine was damaged in a knife attack.

"WE COULD FEEL MIST IN THE AIR AS BAT URINE RAINED DOWN."



NECK DEEP IN BAT GUANO

Christopher Grooms is a research technician at the Paleoeological Environmental Assessment and Research Lab at Queen's University in Ontario. He digs through guano to learn about the environmental history of a region.

“

Wherever there's bird or bat poop, that's where I go. I have dug through decades of gull droppings on an island in New York State, 50 years of swift poop in Canada, and a 4,500 year-old pile of bat guano in a cave in Jamaica. The hardest work site involved performing a 60-meter technical climb down into a cave, just as 5,000 bats were leaving for the night. We could feel mist in the air as bat urine rained down. To get a good core sample, I had to

dig two meters into the pile, while fungus gnats, which were attracted to the headlamp, got all over my face. I was covered in sticky bat feces and clay. After a few hours, we climbed out, washed up with some water we packed in, camped at the cave's mouth, and went back down the next morning. The results will be in a forthcoming paper that will examine pollution levels in the bat guano as a result of mining in the area during the last century.”

SLIPPERY TRUTHS

What the data says about the Keystone XL

After it was narrowly defeated in the Senate last November, the proposal to build Keystone XL will likely come before Congress again early in the 2015 session. The 1,200-mile, 36-inch-wide steel pipeline would transport both heavy oil and bitumen—low-grade crudes that need extra refining before they can be made into products such as gasoline—from Alberta's oil sands to refineries on the

Gulf Coast. The pipeline has become a flash point, both for environmentalists and landowners along the proposed route, who have lobbied hard to stop it, and oil companies who have lobbied equally hard to push it through. With each side of the debate so entrenched in its own rhetoric, fact seems inextricable from fiction. But with data, it's possible to cut through some of the often-hyperbolic claims.

STORY AND CHARTS
BY **Katie Peek**

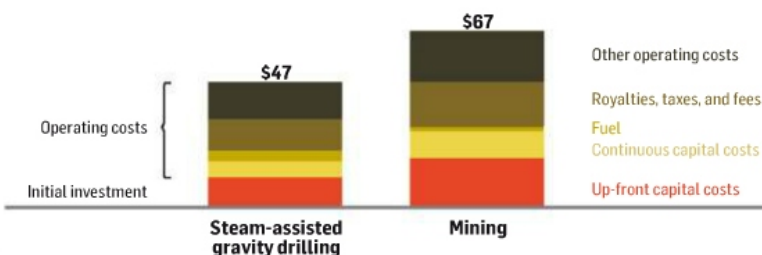
ILLUSTRATION BY
Trevor Johnston

CLAIM

Stopping the Keystone XL won't stop the mining of the oil sands.

Nearly 300 operations have already set up shop in Alberta. Nine of these are mines, where diggers scrape oil sands from the top 250 feet of soil. Another 283 are drilling sites. In about 40 of the wells, engineers pump steam into the sands to heat the oil enough that it flows. Companies have already invested significantly to create those mines and wells. Even if the Keystone XL fails and oil must be transported by tanker or, more expensively, by rail, it would probably be worthwhile for those installations to keep mining anyway.

Typical cost to produce a barrel of crude from oil sands



VERDICT

Existing sites will likely continue operation.

CLAIM

Other pipelines would make up for Keystone XL if it fails to pass.

In the six years since TransCanada submitted its initial application for the Keystone XL, several other pipelines for transporting heavy oil and bitumen out of Alberta have won approval. Some, like the Northern Gateway, will carry crude to ports for shipment overseas. Others, like the proposed Alberta Clipper Expansion, would increase throughput to the U.S. along existing lines. And while the lion's share of crude is still carried by pipeline or ship, rail is fast becoming a viable option as refineries expand their capacity to unload oil cars.

VERDICT

Crude will find a way.

Major pipelines carrying Canadian crude oil



SOURCES, THIS PAGE: CANADIAN ENERGY RESEARCH INSTITUTE; CANADIAN ASSOCIATION OF PETROLEUM PRODUCERS; NATIONAL ENERGY BOARD (CANADA)

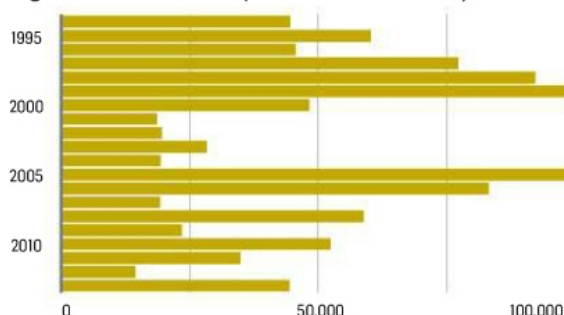
CLAIM**The Keystone XL will pollute the environment.**

In the past two decades, significant spills leaked more than a million barrels from the approximately 50,000 miles of U.S. crude-oil pipelines. If that spill rate per mile of pipeline holds for the Keystone XL—opponents claim the more corrosive oil-sands crude would make it higher; supporters claim modern monitoring technology would make it lower—then the Alberta-to-Kansas segment should see about 10,000 barrels spilled in a decade. That's on par with the biggest onshore crude-oil spills in recent history, such as a 1991 pipeline rupture in Minnesota that lost 40,000 barrels, according to the Pipeline and Hazardous Materials Safety Administration.

VERDICT

History says oil will probably spill.

Barrels spilled from onshore pipelines in significant incidents (50 barrels or more)

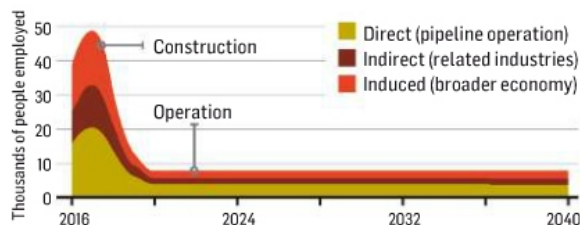
**CLAIM****The pipeline will create many jobs.**

Jobs claims range from wildly high to wildly few, and the truth is probably somewhere in-between. The Canadian Energy Research Institute ran predictions for Energy East, another proposed pipeline. (The project would convert a natural-gas pipeline to carry crude across Canada to New Brunswick.) Analysts estimate the project would generate several thousand sustained jobs, about half of which would be tangential to the pipeline itself—oil-sands miners, or even more tangentially, those who make the goods and services that newly employed pipeline workers buy.

VERDICT

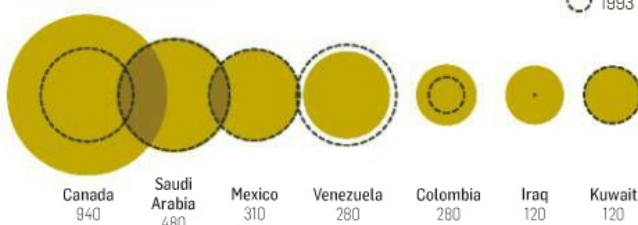
At first. But long term, the pipeline itself will employ relatively few.

Predicted number of jobs created by the Energy East pipeline project

**CLAIM****By allowing the U.S. to import more oil from Canada, the Keystone XL would promote North American energy independence.**

The U.S. has been steadily importing more Canadian crude since the 1990s, and today gets more of its oil from Canada than from all the Persian Gulf countries combined. It's a trend that's likely to continue, given that a fair fraction of the world's petroleum lies under Canadian land—though in difficult-to-extract oil sands (what geologists call "unconventional" form). This unconventional oil will likely get easier to extract as technology improves. The Canadian Energy Research Institute estimates that proposed pipelines, combined with increased rail capacity, could double Alberta's export capacity, about half of which would be U.S.-bound.

Top 2013 sources of U.S. crude imports
Millions of barrels

**VERDICT**

Yes, by augmenting the growing transport network.

TAKE A DEEP BREATH

**A TOUR OF ONE OF
THE WORLD'S MOST
IMPORTANT,
LEAST UNDERSTOOD,
POTENTIALLY
DANGEROUS,
POSSIBLY
LIFE-SAVING
SUBSTANCES: **AIR****

BY MICHAEL ROSENWALD

PHOTOGRAPHS BY SAM KAPLAN



THE AIR MAN needs a fresh hit. It's a beautiful summer morning. Dew shines on the grass. Birds chirp. What a glorious day to contemplate the air. I had contacted the air man—he has a name: Steven Welty—because of a faint, bizarrely sweet odor in our new house that had been annoying me for weeks. Nobody else in my family smelled it, not my wife or our kids. They just thought I was crazy, so I called Welty, thinking he could testify on my behalf. He designs airflow systems that prevent the spread of infectious diseases and potential acts of airborne terrorism in hospitals, office buildings, and high-target government buildings.

Though he doesn't make many house calls, my problem piqued his curiosity, so

WE NOW KNOW THAT AS MANY AS 100 INFECTIOUS BACTERIA, VIRUSES, AND FUNGI CAN BE TRANSMITTED BY AIR.

here he is standing on my front lawn. Welty is bald and wiry, and he's a fast talker. He begins many sentences with, "Dude...." He explains that he's virginizing his nose to my house. He had not smelled anything when he first showed up 15 minutes ago. With his nose now primed, Welty pinches his nostrils—to keep his nasal purity intact—and walks through my front door to the foyer, the area with the odor. He releases his fingers and breathes in deeply, as if he is drawing his last breath.

"Dude," he says, "you have an epic nose."

"What do you mean?" I say.

He explains that he can barely smell anything unusual, if at all. This is a theme in my life. As a practicing hypochondriac and obsessive worrier, I often sense danger where others sense nothing. My heart sinks.

"You can't smell anything?" I say.

Welty says there's an odor but it's so faint, so barely noticeable, that people could rent my nose out, like a dog that sniffs for mold.

"Mold Dog Rosenwald," he says. "Dude, that's you."

I briefly consider and reject this new and exciting career. We walk around my house looking for mold, the most typical source of household smells. We check the basement. We check an old fireplace. With flashlights we look into my HVAC system. We don't find anything. Standing in the kitchen, making small talk about my residential air, the conversation turns to the kind of air Welty really worries about.

He tells me about the SARS outbreak in 2003 and how scientists have traced it back to a Hong Kong hotel where one man, Liu Jianlun, infected a number of other guests who then went on to spread the virus around the world. Though there has been speculation that Liu threw up in the hallway, Welty thinks the germs spread from behind his closed door on currents of air. When I express shock at how that could be, Welty introduces these phrases into the conversation: "toilet aerosolization" and "fecal cloud." I imagine a cloud in the sky made of precipitation. Then I imagine a cloud above my toilet made of—well, I'll stop now. I realize I can never unsee this image. He tells me about flu and how people are trying to stop it with, of all things, humidity. He tells me about so-called "superemitters"—people who when they sneeze spread far more germs than an average *gesundheit* situation. He tells me about *Clostridium difficile*, an infection that drifts around hospitals, causing, among other symptoms, "watery diarrhea."

At this point, I'm considering relocating to a bubble.

"I had never thought about any of this stuff," I say.

"Dude, you have no idea what's out there."

So I ask him to take me on a journey through the air.

WELTY LIVES with his wife and son in a two-story townhouse in a quiet northern Virginia suburb, about an hour's drive from the White House. I arrive there early one morning to pick him up for a road trip. We're heading four hours down I-81 to Virginia Tech University to see one of his heroes, Linsey Marr, an environmental engineer who recently won a \$2.3 million NIH grant to study how humidity affects the spread of influenza. But the air man is running late. At his dining room table, I find him stacking books as carry-on luggage for our trip: *Airborne Infection* on top of *Pulmonary*

Deposition and Retention of Inhaled Aerosols on top of *Hospital Airborne Infection Control* on top of *Aerosol Technology* on top of *The Aerobiological Pathway of Microorganisms*.

The covers and spines of the books are beat up and old, like antique copies of *Huck Finn* found at a friends-of-the-public-library sale. They are a perfect metaphor for the study of airborne disease in this country: tattered, old fashioned, vintage. In the 1940s and '50s, when several of the volumes were published, airborne disease transmission was a hot area of scientific inquiry. Measles and

tuberculosis killed people. Penicillin and vaccines were just being developed. Public health experts centered their attention on the air. "Prevention of the institutional spread of airborne contagium should become the first objective of air hygiene," William Firth Wells, a famous but now forgotten biologist and sanitarian, wrote in *Airborne Contagion and Air Hygiene*, another book in Welty's stack. Their foresight was remarkable.

While researching this story, I managed to come down with coxsackie virus, which causes hand, foot, and mouth disease—and a really, really bad sore throat. I sent Welty an email saying how sick I was and he responded, "It's ironic that you're the perfect person to benefit from my expertise." Welty told me that government scientists in the 1960s used coxsackie virus on prisoners to study airborne disease transmission. In one groundbreaking study, two sets of patients were separated by a wire barrier. One set was inoculated with coxsackie. The other wasn't. Large floor fans were arranged to really stir things up. Everyone wound up sick. We now know that as many as 100 infectious bacteria, viruses, and fungi can be transmitted by air, either inhaled as they sail around or ingested after landing on a surface.

But in the '60s and '70s, the growing use of antibiotics and vaccines slowly relegated the study of airborne disease transmission to benchwarmer status. "Doctors had such overwhelming success with antibiotics that they thought it was the end of disease altogether," Wladyslaw Kowalski, an aerobiological engineer and former Penn State researcher, told me. "They no longer cared much how it was transmitted because they had the cure for everything." Airborne disease conferences dried up and so did research dollars. Ear infection? Here's a pill. Strep throat? Here's a pill. Flu? Here's a needle, roll up your sleeve. Disease prevention turned into signs in bathrooms that say, "Did you wash them? Hand washing prevents disease." The signs are often accompanied by a smiley face.

In the last decade or so, two events have reawakened interest in the moribund field. The first was SARS. The initial outbreak at the Hong Kong hotel was bad, but the most chilling incident occurred in an apartment complex called the Amoy Gardens. There, a single man with really bad diarrhea infected 321 people, killing more than 40. Scarier still, he did it from the solitude of his own bathroom. Welty and other airborne disease specialists have pointed to either the building's plumbing or fan system (or both) as spreading virus-laced droplets through the

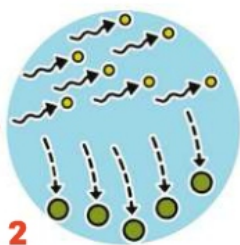
Secret Life of the Flu



1

SNEEZE

A person with the flu sheds infectious particles by showering, making a bed, using the toilet, or simply walking around. But expiration—sneezing, coughing, and breathing—is the most effective way to spread the virus. In addition to creating protective droplets of moisture, a sneeze hurls those droplets into the air at high speed, spreading them far and wide.



2

AEROSOLIZE

For an expired droplet to travel (instead of just falling to the floor), it needs to be small. And that's where humidity comes in: On a dry day, a large droplet will evaporate as it falls, becoming small enough to aerosolize. On a swampy summer day, that same droplet will settle to the ground, limiting its ability to infect a new host.



3

DISPERSE

Air laden with droplets of flu-bearing mucus sails through ventilation ducts, classrooms, and airplane cabins. Dispersal becomes a race against time: Influenza can stick around for a while but it is damaged by heat, light, and ozone (and that's provided it survived the initial stress of being coughed up).



4

LAND

The viral pathogens must land on their host—a step epidemiologists call exposure—in sufficient numbers to actually create a new infection. That process can be helped along if the virus lands on a mucus membrane—like inside the lungs, on the eyelids, or in the mouth.



5

INFECT

If the flu has reached its new host in numbers sufficient enough to initiate an infection, potential victims have a few last chances: A strong immune system, antibodies from a previous infection, and vaccines can all ward off the virus. But if those lines of defense fail, the chills and fever will set in, and with every sneeze the transmission cycle will begin anew.

Influenza, like most airborne pathogens, must endure a perilous journey as it travels between hosts. When the virus leaves the body, it is encased in fluid. That droplet must be small enough that it can be carried by air, but large enough that its protective shell of moisture won't evaporate away entirely—because if the virus dries out, it will likely die. Here's how influenza strikes that delicate balance to infect up to one in five people in the U.S. each year. **KATIE PEEK**

SO HOW CAN HUMANKIND FIGHT BACK?

Vaccines and medicines are one approach, but it's also crucial to understand precisely how flu spreads. Amir Aliabadi is a mechanical engineer whose research into the mechanics of sneezing led him to build a sneeze machine at the University of British Columbia. He thinks experiments in hospitals and other hotbeds of infection could help reduce transmission. Occupational hygiene workers, for example, could use the results to better arrange beds in a hospital. Laboratory studies are too simplistic, Aliabadi says. "This ties into fluid mechanics, biology, epidemiology, and building design. It's a very hard problem."

air, infecting unwitting neighbors who breathed the stuff as it crept through open windows on a beautiful Hong Kong night. A *New England Journal of Medicine* paper in 2004 pointed out, "The SARS epidemic provides an opportunity for the critical reevaluation of the aerosol transmission of communicable respiratory diseases."

The other event rekindling interest in airborne disease transmission is the rapid and frightening—especially to hypochondriacs like me—microbial resistance to everyday antibiotics. The World Health Organization says, "A post-antibiotic era—in which common infections and minor injuries can kill—far from being an apocalyptic fantasy, is instead a very real possibility for the 21st century." So not only are there viruses to worry about—the influenzas, measles, and rhinoviruses of the world—but air contains increasingly antibiotic-resistant forms of tuberculosis, pneumonia, and whooping cough, just to name a few.

Airborne disease adherents say that even the threat of a post-antibiotic era should re-align our thinking with the pre-penicillin

days, when airborne disease transmission and prevention was a more appreciated concept. In practice, however, the old way of thinking—by which I mean generally ignoring the air—still dominates. Welty and other airborne disease specialists refer to those who don't fully embrace the potential terror lurking in ducts and vents as airborne deniers. They point fingers at even the most hallowed of institutions, including the Centers for Disease Control (CDC). The agency still publicly recommends people wash their hands to prevent the flu despite one of the great highlights of the air man's life: In 2009, as the H1N1 virus swept through schools and nursing homes, a CDC spokesman admitted to CNN that, "We don't have solid data on the effect that hand washing has on the transmission of H1N1." The reason, according to virologists, is that flu isn't stable once on your hands; it breaks down and becomes less infectious. The air is where it hides, which is why the air man loads his old books in my trunk, like Linus with his blanket, and we drive down to see Linsey Marr at Virginia Tech.

I**NTERSTATE 81** is a scary stretch of highway packed with long-haul truckers zipping north and south. I grip both hands on the steering wheel. The air man sits next to me, periodically dipping into the back seat, where he has stashed several large portable file cabinets containing perhaps thousands of airborne disease research papers. (The books are weighing down my trunk.) Welty, who is 55 years old, came to his specialty late in life. After graduating from Wake Forest University with a degree in economics, his careers included running a Washington, D.C., limo company that used old London cabs, inventing a fat-free yogurt muffin (called the Yogin), and investigating mold in people's homes. He is a rather obsessive person, and studying mold led him to appreciate the air, which led to collecting and reading hundreds of old books about airborne disease transmission, which led to numerous classes and certifications in indoor air and filtration. Welty has briefed top federal officials, including those at the Environmental Protection Agency, and designed a bioterrorism protection system at a secure building in Washington, the address of which he can't disclose.

In many ways his career is possible because of how we built our modern world. Air flows around us like an unseen, living river. Yet we have constructed our homes and cities and office parks with little appreciation or understanding of it, ignorantly erecting dams, dikes, and tributaries for air with slim thought for the consequences. In the old days, fresh air flowed pretty freely through huts and homes, and the sun's rays fried many of the bad bugs. Now most new office buildings don't even have working windows. As homeowners, we are so energy conscious and fearful of our precious heated air escaping that we don't allow any fresh air to come in. We just recycle the stale stuff over and over again. The germs must love what we've done with the place.

In the car, Welty and I discuss some of the papers in my back seat, which he's also been sending me for the past few months. I tell him one of my personal favorites is "Lifting the lid on toilet plume aerosol," a title you probably don't want to ponder if you have someone in your house with an upset stomach. The paper summarizes dozens of studies on what happens after a sick person uses and then flushes a toilet. For purposes of metaphor, imagine a salad spinner—you cover it while spinning to stay dry. "Aerosolization can continue through multiple flushes to expose subsequent toilet users," the paper says. "Some of the aerosols desiccate to become droplet nuclei and remain adrift in the air currents." It is thought that Norovirus, SARS, flu, *C. diff*, and microbes from many other ailments poof up into the air from toilets and settle onto nearby surfaces or waft through ventilation systems.

A few weeks after our trip, I called the paper's author, David Johnson, an environmental health professor at the University of Oklahoma. "I'm certainly more

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leery of public toilets," he told me. One thinks that flushing a toilet gets rid of whatever is in it. One is wrong. After flushing toilets in a lab setting, Johnson found that bacteria are still there, potentially launching from the bowl, after 24 flushes. Closing the lid doesn't necessarily do any good. He pointed me to a study in the United Kingdom that simulated an attack of acute diarrhea in a test toilet; it showed microbes could escape even with the lid closed. "Although splashes would probably have been contained by closing the lid," the authors wrote, "there was a gap of 15 mm between the top of the porcelain rim and the seat, and also a gap between the seat and the lid of 12 mm, which would allow aerosols to escape into the room."

There are ethical limits on testing that have hampered many modern efforts to figure out how people are being sickened by the air. Johnson can't sit a sick person down on a toilet at Grand Central Station and mount a modern-day coxsackie experiment, for instance. So, what should one do about



the potential threat? In the case of toilets—an obvious fixation of obsessives like myself—I asked Kenneth Mead, an engineer at the CDC’s National Institute for Occupational Safety and Health. One obvious idea, he said, is to eliminate the gap between seats and lids. But this, of course, would represent a fairly significant design challenge for the toilet industry. Building engineers might also consider placing ventilation fans on the floor to suck infected air down, rather than installing overhead exhaust systems that circulate it into a rising tornado ready to be inhaled.

For that matter, designers could reexamine airflow in HVAC systems and buildings, and even down city streets. They could also consider the other primary source of transmission, the mouth, which is a quite scary weapon, particularly with flu. Werner Bischoff, an infectious disease expert at Wake Forest, published a study last year in which he sampled air in an emergency room. His team found flu virus in the air as far as six feet from an infected patient’s head. The real stunner was that of the 61 patients with flu, five of them emitted significantly more virus than the others. Bischoff called these people superemitters and he suspects they are responsible for 80 percent of infections. The problem, Bischoff told me, is that there is currently no way to know who these superemitters are or how to stop them.

That’s where Linsey Marr’s work might help, particularly during nasty flu seasons, which the CDC has decreed this one to be (the dominant strain is especially virulent). Scientists studied humidity in the golden days of airborne disease inquiry, but it’s only in the past five years or so that Marr and other researchers have taken it up seriously again. The research is difficult because

it involves not just biology, but chemistry, aerosol science, and industrial engineering. The research-industrial complex tends to keep subject areas segregated, making funding and collaboration difficult. Marr is unusual in that she has managed to recruit researchers with biology and chemistry backgrounds to her lab.

After a couple stops for coffee, muffins, and beef jerky (I cannot make a road trip without some), we arrive at Virginia Tech. Marr meets us outside her lab building. She is tiny and perky and ready to chat about air. It’s lunchtime, so she suggests we walk a few blocks to a sushi restaurant, which doesn’t seem like a great place to potentially discuss fecal clouds, but really, is there a good place? We find a corner table and order drinks. Welty and Marr bond.

“There are tons of airborne deniers,” Welty says.

“It’s all about washing your hands,” Marr replies.

Marr, who is 40, became interested in the air as an undergraduate at Harvard; during runs along the Charles River she wondered what the smog was doing to her lungs. These days she has young children whom she sends to day care (the epidemiological equivalent of a war zone). Even though the teachers are obsessive about cleaning surfaces and washing hands, Marr noticed that it seemed to have little effect on pathogen transmission. “My kids were getting sick all the time, so I started reading the scientific literature,” she says after we order our sushi, “and I was really surprised how little is actually known about it.”

Marr decided to run a series of experiments. In one, she collected mucus from a 1 month old, her daughter, and added flu viruses to it. She kept the samples at various humidity levels. Below 50 percent humidity—your average heated building in wintertime, without a decent humidifier—the mucus dried up but the virus survived quite well in the air. But above 50 percent, the virus became inactive. The droplets didn’t fully evaporate, leaving a mixture of virus and mucus that’s too salty or too acidic to survive for long.

So, I ask, “What should schools be doing?”

Schools should increase their humidity, she says, as should hospitals. “If you keep humidity in a certain range, I think you could probably cut down transmission by a lot.” But that work is tricky: Older studies have shown that dryer air prevents the spread of other viruses, such as the common cold. Marr needs to figure out exactly how far to turn the dial.

Marr then mentions another study she’s working on, this one about how viruses settle to the floor as dust.

“What does that mean?” I ask.

“That means a sick person could have cleared out of the room, along with the air, but if the person was coughing and sneezing and stuff, the virus might have settled on the floor. New people come in, they walk around, and they kick up the dust.”

I suddenly wonder if any air is safe.

Marr brings up her husband, who is 6 foot 2 and rarely falls ill.

“The kids get sick all the time, and I get sick whenever they’re sick. And so I’m thinking he’s up there breathing air that we don’t—maybe the viruses that we pop out don’t get up to his nose because they all kind of settled out,” she says. “So I had this hypothesis that maybe shorter people get sick more often because they’re exposed to more viruses resuspended from the floor. We want to go do measurements now to see if this really exists.”

I ask what her husband thinks of that.

“He is skeptical,” she says. “He just thinks he has a different immune system or something.”

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Choose Life Grow Young with HGH

From the landmark book *Grow Young with HGH* comes the most powerful, over-the-counter health supplement in the history of man. Human growth hormone was first discovered in 1920 and has long been thought by the medical community to be necessary only to stimulate the body to full adult size and therefore unnecessary past the age of 20. Recent studies, however, have overturned this notion completely, discovering instead that the natural decline of Human Growth Hormone (HGH), from ages 21 to 61 (the average age at which there is only a trace left in the body) and is the main reason why the body ages and fails to regenerate itself to its 25 year-old biological age.

Like a picked flower cut from the source, we gradually wilt physically and mentally and become vulnerable to a host of degenerative diseases, that we simply weren't susceptible to in our early adult years.

Modern medical science now regards aging as a disease that is treatable and preventable and that "aging", the disease, is actually a compilation of various diseases and pathologies, from everything, like a rise in blood glucose and pressure to diabetes, skin wrinkling and so on. All of these aging symptoms can be stopped and rolled back by maintaining Growth Hormone levels in

the blood at the same levels HGH existed in the blood when we were 25 years old.

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Growth Hormone first synthesized in 1985 under the Reagan Orphan drug act, to treat dwarfism, was quickly recognized to stop aging in its tracks and reverse it to a remarkable degree. Since then, only the lucky and the rich have had access to it at the cost of \$10,000 US per year.

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GHR is a natural releaser, has no known side effects, unlike the synthetic version and has no known drug interactions. Progressive doctors admit that this is the direction medicine is seeking to go, to get the body to heal itself instead of employing drugs. GHR is truly a revolutionary paradigm shift in medicine and, like any modern leap frog advance, many others will be left in the dust holding their limited, or useless drugs and remedies.

It is now thought that HGH is so comprehensive in its healing and regenerative powers that it is today, where the computer industry was twenty years ago, that it will displace so many prescription and non-prescription drugs and health remedies that it is staggering to think of.

The president of BIE Health Products stated in a recent interview, I've been waiting for these products since the 70's. We knew they would come, if only we could stay healthy and live long enough to see them! If you want to stay on top of your game, physically and mentally as you age, this product is a boon, especially for the highly skilled professionals who have made large investments in their education, and experience. Also with the failure of Congress to honor our seniors with pharmaceutical coverage policy, it's more important than ever to take pro-active steps to safeguard your health. Continued use of GHR will make a radical difference in your health, HGH is particularly helpful to the elderly who, given a choice, would rather stay independent in their own home, strong, healthy and alert enough to manage their own affairs, exercise and stay involved in their communities. Frank, age 85, walks two miles a day, plays golf, belongs to a dance club for seniors, had a girl friend again and doesn't need Viagra, passed his drivers test and is hardly ever home when we call - GHR delivers.

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Manual

EDITED BY *Sophie Bushwick*

STATS

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Difficulty



WEAR A HEART ON YOUR SLEEVE

WARNING: This project is not intended for medical use. If your heart skips a beat, go see your doctor!

For help building the heart monitor, check out the wiring diagram at popsci.com/heartonasleeve.



This Valentine's Day, scrap the overrated roses and chocolate for a more personal token of love. By combining a cardiac monitor with LEDs, you can flash a symbol of affection with each heartbeat.

To contract the heart muscle and pump blood, waves of electricity spread through the organ. Two electrodes on the chest, one on either side of the heart, can pick up these electrical impulses. (A third—often placed on the right leg—increases accuracy.) Heart rate monitors typically feed this data to a screen that shows the signal like an EKG. Instead, you can send it to a heart-shaped LED display that will pulse along with every beat. DAVE PROCHNOW

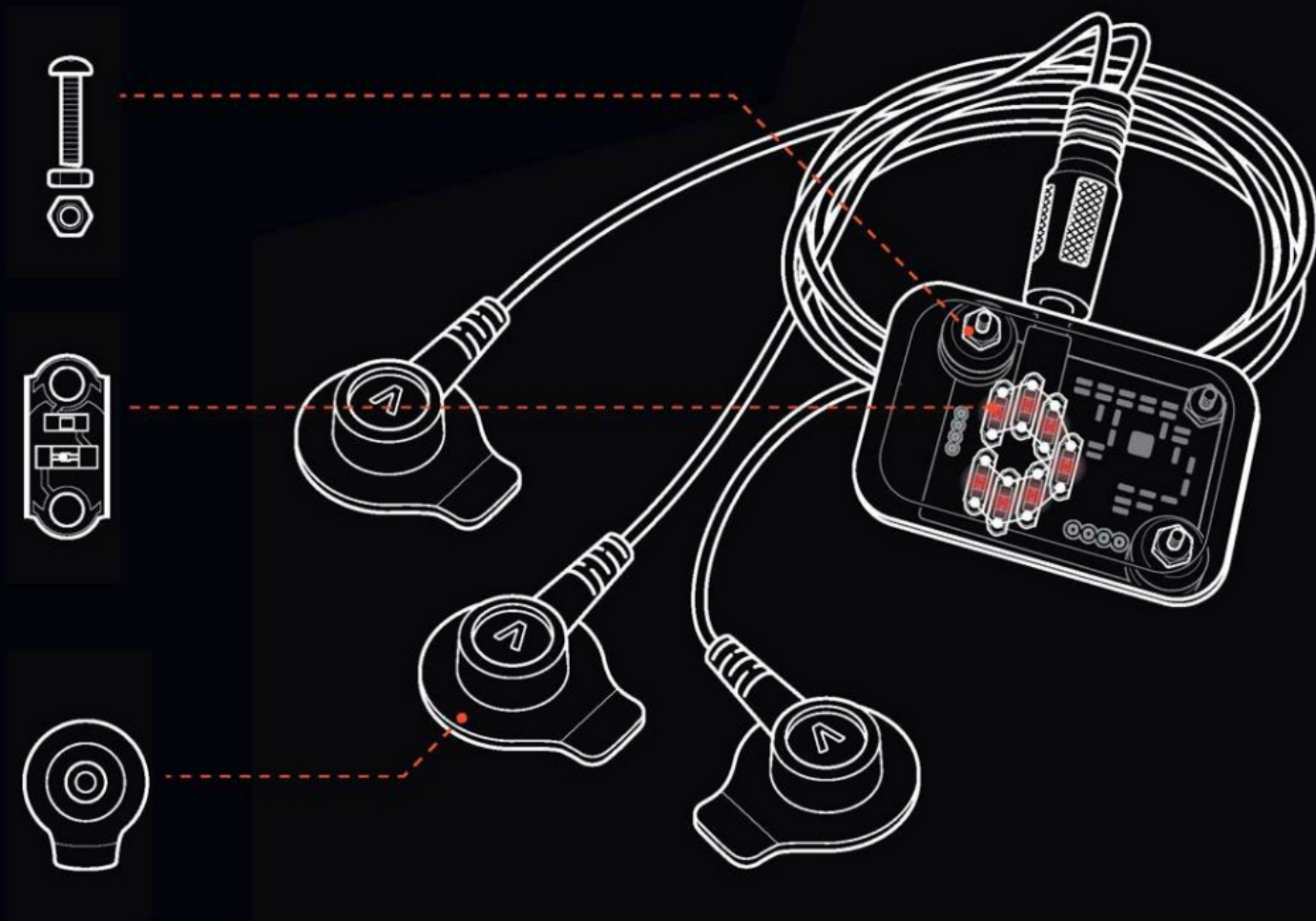
2,838,240,000

Heartbeats in an average human lifetime

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Build It

continued from page 59



MATERIALS

- Scrap of stiff clear plastic, 1 1/8" x 1 3/8"
- AD8232 single-lead heart rate monitor
- 7 red LilyPad LED micros
- Glue
- 3 1/2-inch 4-40 machine screws and nuts
- 7 1/4-inch round spacers
- LilyPad coin cell battery holder
- 3 sensor pads
- Sensor cable with attached electrodes
- CR2032 coin cell battery
- Sheer sock or stocking
- Safety pins

TOOLS



Drill



Soldering iron



Screwdriver

INSTRUCTIONS

1 Place the clear plastic scrap over the heart rate monitor, mark it at three of the four points where there are holes in the monitor, and drill 1/8-inch holes at these marks. Then use a dab of glue to arrange the seven LED micros in a heart shape on the clear plastic. The heart rate monitor's LED should appear in the center.

2 Solder a piece of wire through all of the positive

terminals of the LilyPad LED micros, and connect it to the OUTPUT pad on the monitor. Solder another wire through all of the negative terminals and connect it to the GND pad. Follow the wiring diagram at popsci.com/heartonasleeve.

3 Mount the clear plastic over the monitor with three screws. Slip three spacers around each screw to prevent the plastic from directly touching

the heart rate monitor.

4 Attach the LilyPad coin cell holder to the back of the heart rate monitor with one of the three monitor screws, slipping one spacer between the holder and the monitor. Then solder a wire from the coin cell holder's positive terminal to the 3.3V pad of the monitor and another wire between the holder's negative terminal and the GND pad.

5 Snap a sensor pad onto each cable electrode. Then stick the black electrode on the right pectoral muscle, the blue electrode on the left pectoral muscle, and the red electrode on the upper right leg, just below the waistline.

6 Slip the battery into the holder. The LEDs should begin flashing in time with your pulse. Stuff the assembly into the sock and fasten it to your sleeve.

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THREE BODY HACKS YOU SHOULDN'T TRY AT HOME



ONE

SMELL BETTER

Humans don't stink—it's the bacteria eating our sweat and stomach contents that cause body odor. Avoiding meat and staying hydrated can tamp down some malodorous strains. But a more drastic measure is in the works. Personalized Probiotics is working with Cambrian Genomics to develop genetically modified bacteria that colonize the gut. Following the orders of specialized genes, the bacteria would produce pleasant-smelling compounds to mask the reek of their brethren. "All life is code," says Austen Heinz, CEO of Cambrian Genomics. "Everything is editable."

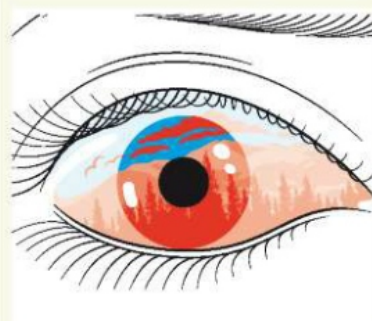
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Maximum current, in milliamps, that transcranial direct stimulation usually applies to the brain

TWO

SEE BETTER

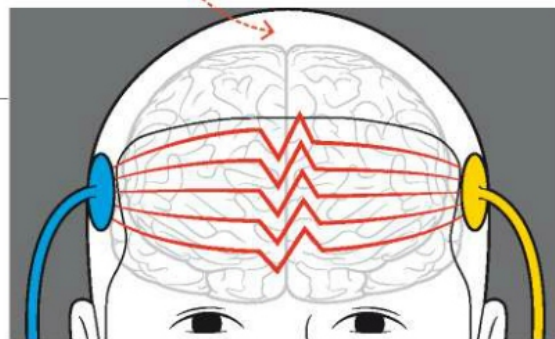
Jeffrey Tibbetts and a group of citizen scientists designed a diet to augment human sight. The all-liquid regimen cuts out vitamin A1, supposedly forcing the eyes' light-sensitive proteins to incorporate vitamin A2 and shifting the visible spectrum. After several weeks, dieters claimed to see near-infrared light, and Tibbetts described perceiving enhanced colors that produced "the most fantastic sunsets in the world." Actual scientists offer a darker view: The diet is more likely to cause deadly vitamin A deficiency than to work.

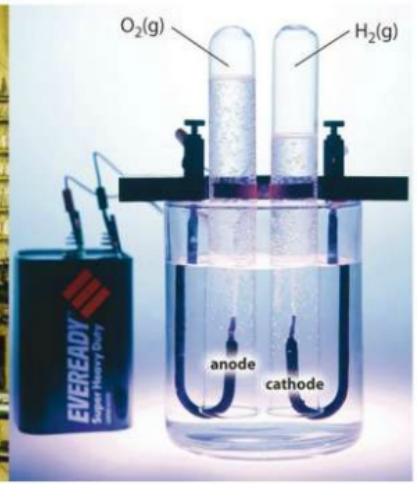
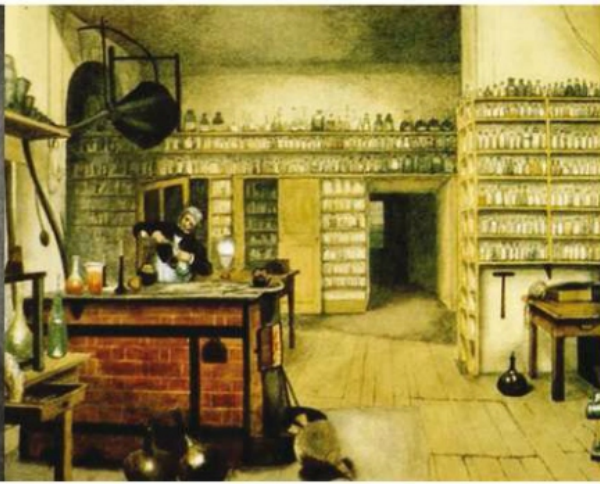
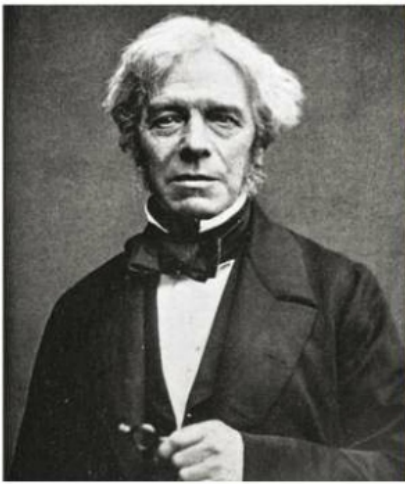


THREE

THINK BETTER

Studies suggest a little electricity across the scalp can relieve pain, increase focus, even tame bipolar disorder. Scientists are still testing the potential of transcranial direct current stimulation (tDCS) in trials where trained professionals use expensive medical-grade devices. Meanwhile, intrepid amateurs are trying to develop their own tDCS tools from nine-volt batteries. These rigs are nothing like those in hospitals and labs, cautions biomedical engineer Marom Bikson: At least one DIYer claimed he went temporarily blind.





HOW MANY MIRACLES DO YOU NEED TO BECOME A BELIEVER WHEN YOU ARE TOLD THEY ARE SCIENTIFICALLY IMPOSSIBLE?

Miracles are always a work in progress that begin with one step. In the 19th century the quest for the purest water began with Michael Faraday's First and Second Laws of Electrolysis. But hypothesizing a law mathematically is not the same as actually achieving the results. Stepping into Faraday's shoes some 40 years ago was Electrical Engineer John Ellis who succeeded in doing what no inventor has done before or since—he perfected the distillation and purification of water—altering the bond angle of the hydrogen in the water from 104° to 114° creating what a Washington Post writer referred to in 1992 as “light water” and what most simply call “miracle water.”

I started a scientific controversy when I finally changed the properties of ordinary water into “MIRACLE WATER” by increasing the Hydrogen Bond Angle in ordinary water from 104° to a measurable 114° and maintained it! However, text books will tell you this is “IMPOSSIBLE” because like any substance, as a result of that change it's not water anymore, it's something else but if you are a believer you know with God anything is possible!! Scientists have said for years that if anyone could do that it would “Cure Anything” and at 85, after being in this family business for 40 years, we have thousands of reports that it HAS!! Even during the development stage, as far back as 1/27/92 a Washington Post Investigative article (on my website) noted 10,000 people/day travelling to obtain my water! Do I want everyone to use my water? The short answer is NO because Bill Gates and many others have said we have to depopulate the planet down to 500 million (only those people that believe in God's miracles will survive)!

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HERE'S PROOF why they say it's “impossible”: Jon Spokes at The Washington Times received a phone call from the top scientist at the Los Alamos Nuclear Lab with so many degrees after his name he needed a fold out calling card: “You have a scam artist advertising the impossible in your newspaper!!” which was followed by scientists from

Lawrence Livermore and the Fort Detrick Biological and Cancer Institute. Jon Spokes monitors advertisers for honesty to maintain the good name of the newspaper! Accordingly, he told him: “Call John and if you decide he's a scam artist, he will never advertise in this newspaper again!” After calling me and buying our E5 machine, he laughingly told Jon: “I am embarrassed to say John HAS CHANGED THE HYDROGEN BOND ANGLE in water and I wish I owned his patents!” Since that time we have sold 100's of machines to these scientists that include Lawrence Livermore and Brookhaven Labs when a nuclear reactor contaminated an aquifer. With an Engineering Degree that includes Steam Plant Design, God proved with his infinite wisdom that I was right and the textbooks were WRONG!

After the above article, G. Abraham MD did independent Blood Flow studies at UCLA Medical School since blood is 94% water: “You can't argue with something you can measure. Nothing is even close to your water in getting blood to the extremities!” However, charlatans have bought my machines and used my “Miracle Water” on religious TV and since we can measure the 114° HBA we can see if it's our misbranded water! In some cases, it tests out as tap water!! Also, BOTH ordinary distilled (101° HBA) and ordinary water (104° HBA) have ZERO ENERGY!! Our 114° HBA water has 3000% MORE ENERGY and we can measure that also (website Ammeter Video adding ONLY 20 DROPS to ordinary water)! 94 year old Gilbert de Daunant (Prince Rainier's cousin), after shipping a machine to an MD in Africa: “Your water is working against EBOLA both in and out of the hospitals!” Since this energy boosts the immune system, we want to reach as many people as possible as a humanitarian effort. Accordingly, I am putting my properties into a nonprofit and using TV for further outreach. Our gorgeous 418 acre mountain property overlooking the Delaware River is perfect to evangelize this discovery! With its one of a kind Gatehouse and Pavilion including miles of roads with estate lighting and underground utilities to protect the visual beauty, this is a unique setting for visitors. We hope you will join us! 13 Patents 332 FDA Tests. Johnellis.com/measure

• Written by John Ellis

Gilbert de Daunant (Prince Rainier's cousin): “I just walked 40 blocks and I am 94! Send another E5 to Monaco!”

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Eight-year-old “Little Cool Hand” Luke was born without a left hand. “Luke used to be shy and sometimes hid [his arm] behind his back,” says his father, Gregg Dennison. “Now, he shows off his 3-D-printed hand. It boosted his confidence and has definitely been a game-changer.”

LET'S GIVE THE KIDS A (3-D-PRINTED) HAND



One in 1,500 children is born with a partially formed upper limb. But for every child who receives a prosthetic device, hundreds go without. Many families cannot afford a hand replacement, which often costs thousands of dollars, while others find that, after shelling out for a fancy new prosthetic, it performs poorly or the child outgrows it.

Now, a volunteer-driven movement is striving to solve that problem by creating cheap, durable 3-D-printed hands. Coordinated by an organization called e-NABLE, the effort has so far distributed more than 400 plastic hands, which can be printed in a range of colors and go by names such as the Raptor Hand and the Cyborg Beast.

Through the group, volunteers who own

3-D printers and people in need of hands can connect. Recipients enter their measurements into e-NABLE's “Handomatic” software, which makers can use to customize an existing design. Or they can create a unique model based on the Handomatic file. Once a printer churns out the parts, the hand takes just a few hours to assemble.

“There are opportunities for everyone to get involved—from hardware geeks to parents to kids,” says Jon Schull, a research scientist at the Rochester Institute of Technology and the founder of e-NABLE. In less than two years the group has grown exponentially, from 70 members to about 3,000, and it's still expanding by roughly four percent each week.

HOW IT WORKS

The Raptor Hand uses a simple tension mechanism: Strings run along the undersides of the fingers to the top of a gauntlet. When the wrist

bends, the strings act as tendons, opening and closing the fingers with enough precision for some users to hold spoons and eat cereal.

Schull wants even more people to get involved. “It's a big world, and there's an amazingly large number of people who could really use an artificial hand,” Schull says. “We've delivered only a very small drop in a very large bucket.” **RACHEL NUWER**

That's a Job

ELECTRIC BICYCLE BUILDER

↓

When Micah Toll moved to Tel Aviv after college, the electric bike enthusiast got a job repairing his favorite form of transportation—in the process, learning all the ways e-bikes break. Now he uses that knowledge to build better models, electrifying regular bicycles at a fraction of a new one's price. **JEREMY COOK**



Toll built his first personal e-bike, pictured here, as a student in Pittsburgh. "I think I owned half the e-bikes in the city," he says. "And I could count mine on one hand."

Why did you start powering bikes with electricity?

I went to college in Pittsburgh, which is very hilly, and I needed a good way to get around. I tried a gas motor-powered bike, but it was dirty and noisy. An electric motor was better: quieter and without the smell.

Will e-bikes become more popular?

Definitely. Commuters in Tel Aviv

have really embraced e-bikes as an alternative form of transportation, an option for getting out of cars. People in the U.S. are mostly buying them for pleasure riding, but that's how it starts. If the patterns of adoption across Asia and Europe hold true, the U.S. is right on the cusp of a large wave of e-bikes hitting the streets.

Can I convert my own bike?

That's the subject of my e-book, *The Ultimate Do-It-Yourself eBike Guide*. It isn't hard. If you've ever changed a bike's inner tube, you've already done half the work.

COURTESY MICAH TOLL (2)



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On the ground floor of Pioneer Works Center for Arts and Innovation in Brooklyn, New York, a bearded and flanneled trio played gloomy arrhythmic music one Wednesday night. Upstairs, director of education David Sheinkopf taught a class on the science of sound, including how to build a core technology behind the performance below: the electronic speaker. *Popular Science* sat in to learn about harnessing sound with a little DIY. **RAFI LETZTER**



THE LESSON PLAN

In a speaker, an audio signal sends current through a coil, creating a magnetic field that yanks on a second magnet. This vibrates a diaphragm, sending sound waves through the air.

Students build stripped-down speakers from magnet wire, which coils up to form the electromagnet; a Post-It note, which acts as the diaphragm; and a rare-earth magnet taped to a tabletop.

Alligator clips attach the contraption to a speaker cable, which plugs into a cellphone to play music at a low volume. If you press your ear to the makeshift system, the quality is surprisingly good.

In addition to speakers, students learn the history of analog sound recording, from before Edison to beyond cassettes, and construct makeshift record players out of pins, pencils, and paper.

To build your own DIY speaker, visit popsci.com/paperspeaker.

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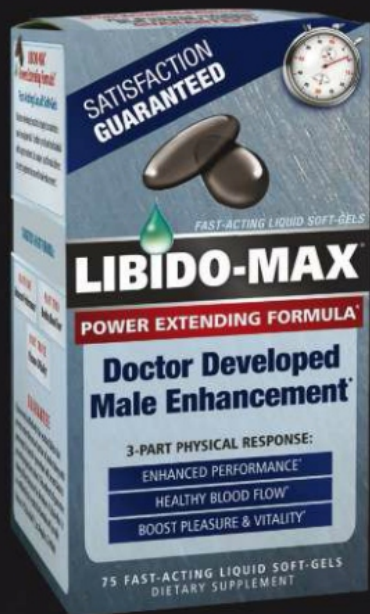
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ANSWERS BY **Daniel Engber**

ILLUSTRATIONS BY **Jason Schneider**



Can body fat protect you like a built-in cushion?

Short answer It prevents some injuries but causes others.

A

Fat can indeed act as a shock absorber in violent collisions. A 2003 study of car-crash victims found that those with more subcutaneous fat were less likely to suffer abdominal injuries. But the fat-as-airbag principle only goes so far. When a driver is flung forward, the heavier his or her body, the greater the force required to stop it.

"Changing demographics create challenges to seat-belt fit," says Richard Kent of the University of Virginia Center for Applied Biomechanics. Restraints have long been designed using crash-test dummies, whose size—about 168 lbs. and 5'7" tall—doesn't correspond to most Americans today. (Though one of the world's leading dummy producers recently announced

plans to release an obese, 271-lb. model.)

The pelvis is the primary load-bearing structure for seat-belt safety, Kent says. But with big stomachs, seat belts slide up and off the lap. Since a restraint works best once it engages with the skeleton, any time it spends pressing into soft tissue will delay that protective effect.

To observe this, Kent defrosted eight cadavers and belted them into car seats for a 30mph crash. High-speed video showed that the obese bodies flew off their seats pelvis- and lower-chest-first. Smaller subjects' hips stayed in place as their heads and torsos pitched against the upper harness. That may help explain the pattern of injuries typically seen in obese crash victims—more damage to the legs, less to the head, and a greater likelihood of death.

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HOW BIG WOULD A METEORITE HAVE TO BE TO WIPE OUT ALL HUMAN LIFE?

Short answer 60 miles wide, give or take



A

When it comes to meteorites, the bigger they are, the more havoc they generally wreak. In 1997, University of Colorado geoscientist Brian Toon and colleagues predicted the aftermath of meteorite impacts of various sizes. They found that a space rock half a mile wide would produce an explosion that releases the energy equivalent of up to 100,000 million tons (Mt) of TNT. That's enough to cause widespread blast damage and earthquakes, but nothing too out of line with many natural disasters in the modern age. Once a collision exceeds the 100,000 Mt threshold, you're looking at a catastrophe larger than any in human history. A meteorite a mile in diameter might send enough pulverized rock into the stratosphere to block out sunlight and cause global cooling.

The object that killed off the dinosaurs was probably seven or

eight miles wide, says Jay Melosh, a planetary physicist at Purdue University. Its impact would have ejected a dust plume that spread clear around the planet and rained blazing-hot on to forests, igniting them. "The dinosaurs probably broiled to death," he says.

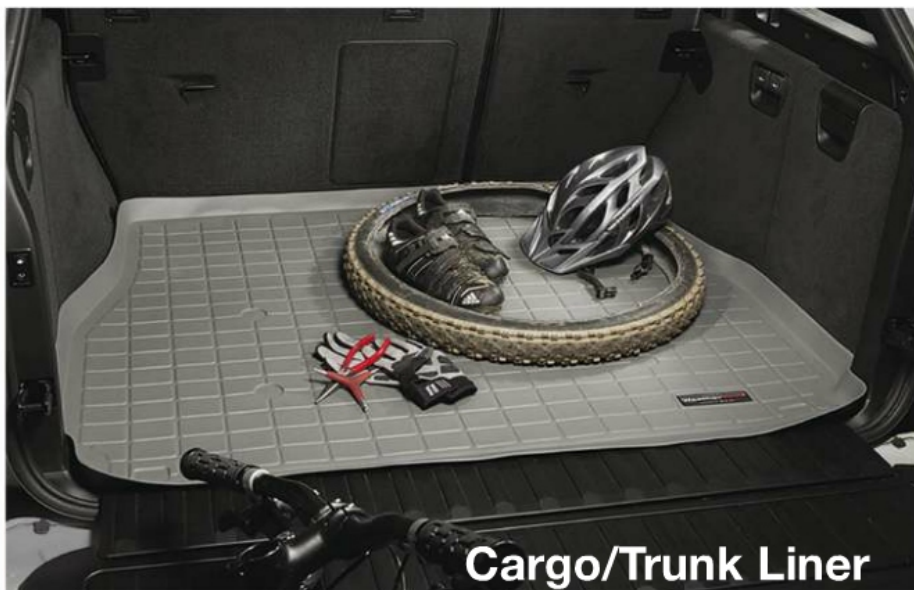
Such a collision today would kill billions of people. Those who didn't perish in the initial blast or the fires that followed would face long odds of finding sustenance. "People are going to starve to death," Toon says. Still, a few would likely weather the apocalyptic storm. "Probably some fishermen in Costa Rica," he offers. "People near the oceans who managed to hide out and fish when the fires started."

For a collision to obliterate the human race altogether, Toon estimates it would take a 60-mile-wide meteorite. He says, "That would incinerate everybody." ❧

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ET, but it would tell you exactly where to go back—this time with a microscope.

AS WE ARE TALKING, I FIND myself in the middle of a very different kind of conversation about the nature of life. At one point, Neelson pauses to inform other members of the lab that a close friend and colleague, Katrina Edwards, died over the weekend. Then he interrupts again, explaining that he has to drop off his retirement papers with the dean, easing himself into a four-year exit. When Neelson returns, he indulges in a little reflection. His only real regret, he tells me, is that he won't have enough time to study Rowe's all-electric bacteria himself: "It really pisses me off that I discovered this when I was 70 years old, because it's important."

Electrically active bacteria could have many practical benefits that research-

ers are now beginning to explore. They turn out to have an incredible talent for sewage treatment, for example. Stick an electrical anode in human waste and it attracts communities of bacteria that eat feces and breathe electrons. Hook them up to a fuel cell and you have a self-powered wastewater treatment system that produces significantly less sludge. One of Neelson's former students, Orianna Bretschger, set up a test system at the J. Craig Venter Institute in San Diego, where it's been running for five years with practically no maintenance. "My personal goal is developing these systems to a point where we could fly them into villages in the third world," says Neelson, who still collaborates with Bretschger. "People would bring their sewage to the treatment plant and get clean water, and you wouldn't need any outside power."

Daniel Bond at the University of Min-

nesota is exploring the potential for electric bacteria to generate power and synthesize novel materials. The defense department is reportedly interested in underwater sensors driven by bacteria. El-Naggar suspects that electrical interactions between bacterial and human cells may have important, almost entirely unexplored health implications. After all, the sewage experiments indicate there are electrically active bacteria in the gut. He wonders aloud: Do they communicate with human cells as part of the body's internal ecosystem?

All of these possible applications derive from the sheer unfamiliarity—the utter alien-ness—of *Shewanella* and its even stranger cousins. They are alien not just in what they do but in how they do it. Their Earth seems to be a world built on cooperation and sharing, a far cry from the more familiar world of cut-throat Darwinian competition. "Unless I miss my bet, that's what we're going to see when we get to the subsurface: little pockets of life with a socialist community, all working there together. But I won't tell that to my Republican father because he won't like it," Neelson says.

I think of electric socialism as an exotic idea, but Neelson quickly convinces me otherwise. It may be the normal way things work in environments where resources are scarce and predatory competition is not an advantage. It may have been life's reality through much of its history on this planet. ("I always thought that bacteria never learned to grow fast until predators evolved," he says. "What's the rush? You know, bacteria don't eat other bacteria.") In fact, it may suit more of today's life than most scientists realize, since so much of Earth's microbial ecosystem is still out of sight. By some estimates, 99.9 percent of all species cannot be cultured in a petri dish. Slow, collaborative living may be life's way on many other worlds as well.

That's a lot of maybes, so I put this to Neelson: Does he really believe in a shadow biosphere, built around electron sharing and microscopic collectivism? "Before I kick the bucket, I hope that is proven to be true," he says. Then he corrects himself, like a proper open-minded scientist. "I mean, I don't. It's okay with me if it's not true, but I'll be really surprised. It makes so much sense, and life usually makes sense." **PS**

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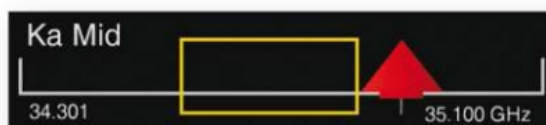
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TAKE A DEEP BREATH

A look at one of the most common ways that germs spread in homes and schools, and how to protect yourself from them.

T

Take a Deep Breath

continued from page 57

A FEW MONTHS after our trip to Virginia Tech, Welty drops by my house one weekend. We are looking again for the odor, which my wife now acknowledges might possibly exist (or at least does not want to argue about anymore). We rented a portable olfactometer and I'm on the floor wearing a mask and sniffing around. The mask is attached to an oxygen tank that pipes in fresh air. The idea is if I locate something funky, I'll know because it will overtake the fresh oxygen. I don't find anything, and that, I realize, sums up the predicament with air: Though it is all around us, we can't easily see what's in it. So as a society, we ignore it. Before I met the air man I had not spent any significant time pondering the air. Neither had my wife, and she's a family doctor, whose business is to protect people from sickness.

There are tools to fight airborne disease, of course, but they are fewer than you'd expect and relatively arcane. When Welty is hired, for example, he often recommends ultraviolet lights (UV) in HVAC systems to cook microbes as they pass through. But even these systems are not perfect, and they can be prohibitively expensive. Some hospitals are beginning to send robots into recently vacated rooms to flash-fry every surface with intense pulses of UV light. Certain companies are now pushing ventilation systems that mix in natural air, but those, again, are not cheap.

When Welty first came to my house, he leant me a cold plasma system for my HVAC system—a tiny box with two sticks the size

of crayons sticking out. One generates positive ions, the other negative. As air passes by, the electrical charge attracts microbes and, according to the manufacturer, robs them of hydrogen, killing them. We also installed a UV light. The devices haven't yet eliminated the odor—at this point, we're considering replacing the hardwood floors—but my wife and I have noticed fewer colds.

Welty is under no illusion that such measures are a panacea, rather, they are Band-Aids on a larger problem. What people like he and Marr want is a full-scale appreciation for the dangers of airborne disease transmission and how we might deal with them.

Right now that's a lonely conversation. Down at Virginia Tech, as we get ready to hit the road, Welty invites Marr back to my car so he can show her all of his books. I open the trunk and she says, "It's like a traveling library."

"Have you seen this one?" Welty says, holding *The Aerobiological Pathway of Microorganisms*.

"That's a classic," Marr says.

He shows her a collection of papers from an old airborne conference in the 1960s. She's impressed he has original copies.

"They were having conferences on this stuff up until, like, 1980," he says.

"And they just stopped," she says.

And then he hands her a gift: *An Introduction to Experimental Aerobiology*, published in 1969.

He inscribes it, "To my fellow airborne believer." **PS**

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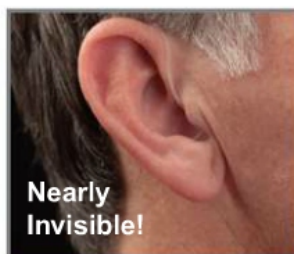
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ALL IN A DAY'S WORK

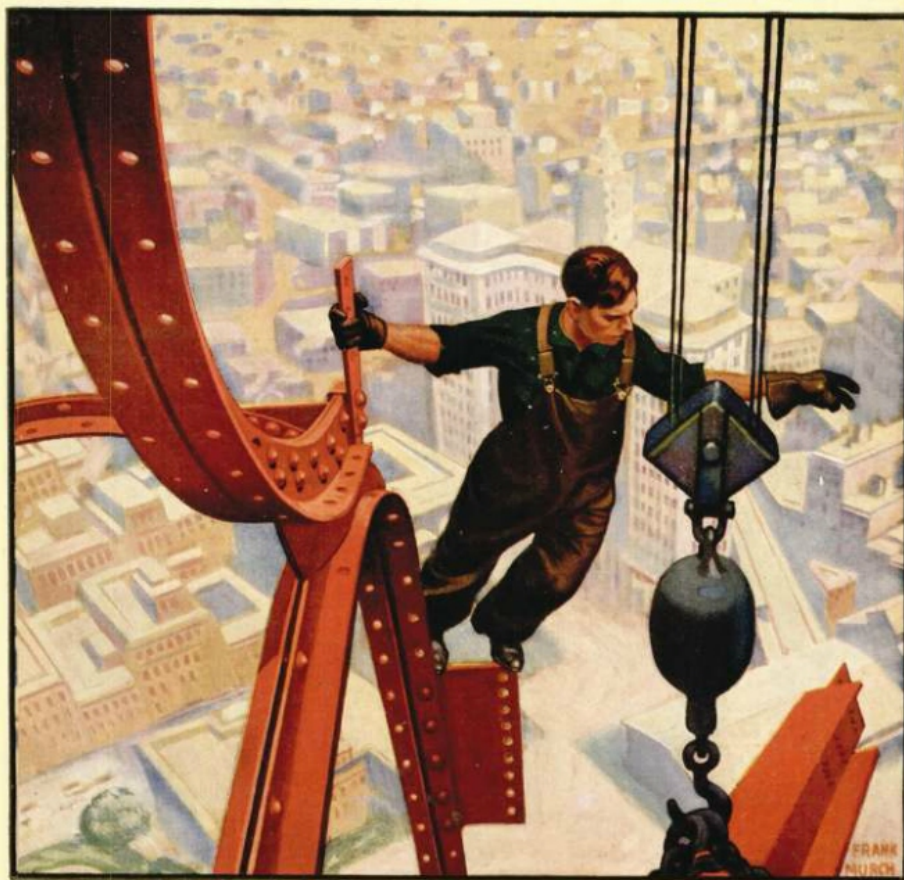
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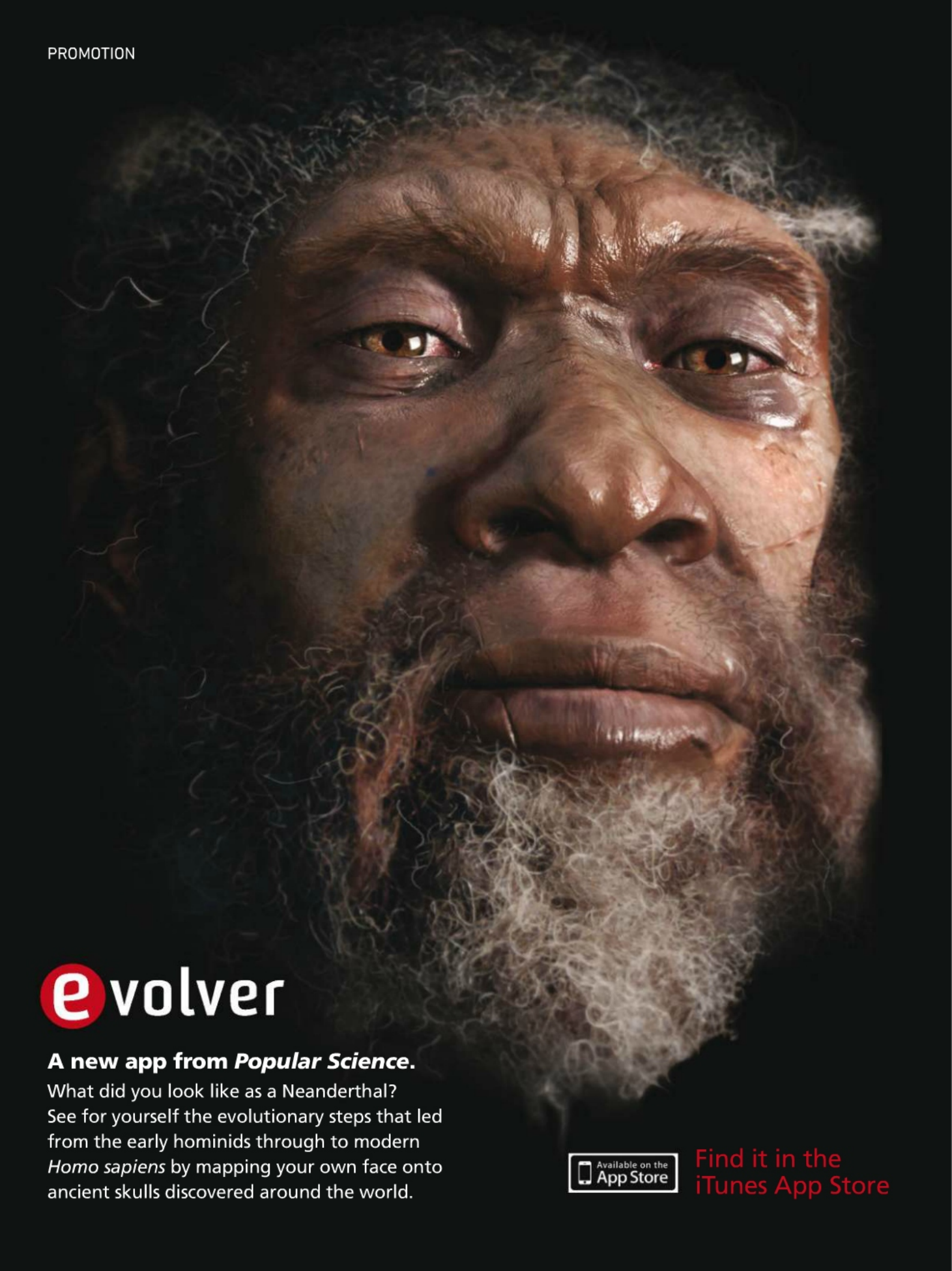


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